Froehlich, Robson, Taniyama

Tests of Reinforced Concrete Beams.

Resistance to Web Stresses

Civil Engineering

B. S.

1909

TESTS OF REINFORCED CONCRETE BEAMS. RESISTANCE TO WEB STRESSES

BY

JOHN DANIEL FROEHLICH

CARL DAVID ROBSON

SADAKICHI TANIYAMA

THESIS

For Degree of

BACHELOR OF SCIENCE

IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

Presented June 1909

UNIVERSITY OF ILLINOIS

June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

JOHN DAVID WILLIAM FROEHLICH, CARL DAVID ROBSON, and
SADAKICHI TANIYAMA

ENTITLED TESTS OF REINFORCED CONCRETE BEAMS: RESISTANCE TO WEB
STRESSES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Civil Engineering

D. A. Abrams

A. N. Talbot

Instructor in Charge

APPROVED: John P. Brooks

HEAD OF DEPARTMENT OF Civil Engineering

1.

Introduction.

2.

Theory and Available Data.

3.

Materials, Test Pieces and Method of Testing.

4.

Experimental Data and Discussion.

5.

Conclusion.

I.

INTRODUCTION.

------0------

The data and conclusions in the following pages are the results of an investigatinn of the effect of the different methods of disposing the steel in a reinforced concrete beam in order to provide for the web stresses developed. In this thesis the object is, if possible, to determine by direct tests the most advantageous method of strengthening concrete beams against failure due to web stresses.

There were ninety three beams tested. The beams were 8 by 10 inches in cross section, varying in span, and in horizontal and vertical reinforcement.

In order to more easily study the results, the tests have been divided into three classes, namely, Classes A, B, and C. Class A includes beams, without web reinforcement, of 6, 9, and 12 ft. spans, and of 1% to 3% reinforcement. Class B includes all beams with webs reinforced by bars bent up near the ends, of a uniform span of 6 ft.; the reinforcement varying from 1.25% to 1.92%. There were also five beams reinforced by 1 in. x 3 in. Kahn bars. Class C consists of beams of 6 and 12 ft. spans, webs reinforced by vertical stirrups or a combination of rods bent up and vertical stirrups. The reinforcement varied from 1.25% to 2.80%.

In the following pages are tables which give all

data observed in the tests of these beams; also in the tests of auxiliary specimens which consists of control beams, compression cubes, and reinforc ing steel.

Curves have been plotted showing the relation of deflection to applied load. Diagrams of the beams are also included, showing the appearance of the beams after failure. All prominent cracks have been shown on the sketches.

All tests were made during the season of 1908-1909 in the Laboratory of Applied Mechanics in connection with experiments on concrete carried on by the University of Illinois Engineering Experimental Station.

Mr. C. D. Robson is responsible for the data and conclusions relating to Class A.

Mr. J. D. Froehlich is accountable for data and conclusions under the head of Class B.

Mr. S. Taniyama is responsible for the data and conclusions relating to Class C.

II.

THEORY AND AVAILABLE DATA.

-------0-------

Preliminary.

Flexure of reinforced concrete beams seems more complicated than is the case with steel and timber beams. For reinforced concrete beams, the theory of the resistance to web stresses, in the beams with web reinforcement is more complicated than is the case with concrete beams without web reinforcement. In the design of the reinforced concrete beams the web members play an important part. As the beam takes the load the stresses between the upper and lower fibres are transmitted by the web members. These web stresses are taken, either by the concrete itself, or the steel reinforcement. There are three kinds of stresses in the web of the beam, namely; those due to the tendency for the longitudinal rein-forcing bars to slip thru the concrete, those due to shear in the concrete and those due to the combination of the shear and the tension of the concrete. These stresses are called bond, shear, and diagonal tension stresses.

Theory.

The following formulae, which were derived by Prof. Arthur N. Talbot, are used in the discussion of these stresses.

The bond stress formula for the longitudinal reinforcement is $u = \frac{V}{m\ o\ d'}$, where u represents the bond developed per unit of area of surface of bar, V the maximum vertical shear, m the number of bars, o the circumference or periphery of one bar, and d' the distance from the center of the reinforcement to the center of gravity of the compressive stresses.

The formula for vertical shear is as follows;
$v = \frac{V}{b\ d'}$ in which V and d' are the same as above, b is the breadth of the beam, and v is the vertical or horizontal shearing stress per unit of the area in the concrete.

The formula for the stress in the longitudinal reinforcement is $f = \frac{M}{A\ d'}$ where d' is the same as above, f is the tensile stress per unit of area in the metal reinforcement, A the area of cross section of longitudinal reinforcement, and M is the resisting moment at the section taken.

In computing the stresses in the beams in Class B , these formulae do not give the actual stresses in the steel at the bent up portion for d' here becomes a variable quantity and therefore gives different results for the derivative from which the formulae are reduced. It is believed, however, that the determination of the actual stresses in the web of a beam with bars bent up is impracticable, and that a readier and more definite idea of results may be had by assuming the bars horizontal in computing the bond and vertical shearing stresses.

In beams in Class C the formulae are used to determine

the stress in stirrups were as follows; $P = \frac{V\ a}{d'}$ in which V and d' are the same as in the above formulae, a is the spacing of stirrups, and P is the total stress taken by one stirrup. In this it is assumed that the concrete does not take tension. The following formula was used to determine bond stress in the stirrups; $B = \frac{P}{0.6\ d\ O}$, P is the same as above, B is the bond stress per unit area of stirrup, d is the effective depth and O is the periphery or circumference of one stirrup. The distribution of the bond stresses on the surface of the stirrups is indeterminate. In the calculation for the bond in the stirrups, the bond surface of the stirrups for a depth of beam equal to 0.6 d, is assumed. The distribution of bond stress developed on the surface of the stirrups in beams with bars bent up is indeterminate. In the calculation for bond in these stirrups, it has been assumed that one half of the vertical shear is carried by the bent up portion of the horizontal bars and the remaining half of the shear is taken care of by the stirrups, assuming that effective depth of beam equals 0.6 d.

Available Data.

Mr. Harding of the Chicago, Milwaukee and St. Paul Railroad, in his tests on beams 12in. x 20 in. in cross section, 12 ft. span, loaded at one third points, .75% reinforcement, and plain, round straight bars secured an average shearing stress, at failure, of 108 pounds per square inch. The data of these tests, as well as those made by Messers. Maiburg, Carson, and

Withey , vary from that of this thesis to such an extent that a ready comparison is difficult. Professor A. N. Talbot has made tests on beams which correspond sufficiently for comparison to the beams used in this thesis. The data of these beams may be found in Bulletin No. 4, 14, and 29. of the University of Illinois Engineering Experiment Station.

III.

MATERIALS, TEST PIECES AND METHODS OF TESTING.

---------0---------

Materials.

In order that these tests might approach the conditions found in ordinary practice, all materials used therein except the steel, were purchased in the open market.

Stone.- The stone used was Kankakee Limestone, ordered screened over 1/4 inch screen and through 1 inch screen. It weighed 83 pounds per cubic foot loose, and contained 50% voids. The following table shows the mechanical analysis of the limestone. The proportion of size was determined from two samples of 2000 grams each.

Table. 1.

Mechanical Analysis of Stone.

Size of Meshes inches.	Per cent passing.
3/4	89.0
1/2	54.0
3/8	31.9
No. 3 Sieve.	15.6
" 5 "	2.2
" 10 "	1.4

In the determination of voids in both stone and sand, the material was poured slowly into the water so that all the voids

became filled, and no air was entangled.

Sand.- The sand was from near the Wabash river at Attica, Indiana. It was clean and sharp, and was screened through a sieve of 1/4 inch mesh before using. The sand weighed 99.8 pounds per cubic foot loose, and contained 46.5% voids. Table 2. shows the mechanical analysis of sand.

Table. 2.

Mechanical Analysis of Sand.

Average of two samples.

Sieve No.	Percent Passing.
3	99.6
5	93.7
10	74.0
12	67.5
16	60.5
18	50.8
30	32.0
40	19.0
50	6.5
74	3.3
150	0.9

Cement.- All cement used in the beams was Chicago A.A. Portland cement purchased from a local dealer.

Table. 3.

Tensile Strength of Neat Cement and Mortar.

Neat Cement.				1 : 3 Mortar.			
Ref.No.	Age days	Percent of water.	Ten.Str. lb.per sq. in.	Ref. No.	Age days	Percent water	of Ten. Str. lbs. per sq. in.
1	7	21.0	721	1	7	9.1	176
2	28	21.0	768	2	28	9.1	254
3	7	20.5	742	3	7	9.0	232
4	28	20.5	783	4	28	9.0	306
				5	7	8.9	205
				6	28	8.9	270

Table. 4.

Fineness Test of Cement.

Standard Mesh.	Percent Passing.
75	97.5
100	92.8
200	74.7

Steel.- The steel used for reinforcement, consisted of 1/2, 5/8, and 3/4-inch mild steel plain round rods, and 1/2 and 3/4-inch round and square corrugated bars. The stirrups were 1/4-inch and 1/2-inch plain round mild steel or square corrugated bars.

The corrugated bars were furnished, for these tests,

by the Corrugated Bar Company, St. Louis, Mo. and the plain round bars by the Illinois Steel Company, Chicago, Illinois. Table 5 shows the results of tensile tests of steel used in these tests.

Concrete.- The concrete was mixed by hand, all materials being measured by loose volume. The operations were as follows: The sand and cement was thoroughly mixed dry. The stone, which had been sprinkled was then mixed with the sand and cement so that the entire surface of the stone was coated. The mixture was then turned thoroughly. The required amount of water for a wet mixture was added, during this operation.

The proportion for all beams was 1 part cement, 2 parts sand, and 4 parts broken stone. The water used was about 8% by weight of this total dry mixture.

Making of Beams. The beams used in these tests were 6 ft.-6 in., 9 ft.- 6 in., and 13 ft. overall, making spans of 6, 9 and 12 ft. respectively. They had a cross section of 8in x 11in. The steel was placed so that its center was one inch from the lower surface of the beam. The distance from the center of the steel to upper surface was therefore 10 inches. The concrete used in all cases was a 1 - 2 - 4 mixture by loose volume.

The beams were made in the concrete laboratory. In most cases two of the 6 ft. beams were made from the same batch

of concrete. They were molded in wooden forms without bottoms, the concrete being deposited on a strip of building paper placed on the floor under the forms. These forms were removed in 7 days and the beams when 60 days old, were moved to the testing laboratory for testing. They were not moved from their original position until due to be tested.

A control beam 6in. x 8in. x 40in. long, and three 6in. cubes were made from each batch of concrete.

Methods of Testing.- The tests were made in the Laboratory of Applied Mechanics, on an Olsen Testing Machine of 200 000 pounds capacity. The beams were set on rocking supports placed 12 to 6 feet apart, according to the length of the beams. Care was taken that the beams rocked freely so as to allow them to adjust themselves under the load. Plates 3 x 1 x 8 inches were placed on the rocker bearings, and a heavy piece of rubber belting was placed between these plates and the beam. The loads were applied at the 1/3 points of the span. At these points a rubber cushion was placed next to the beam, and on this a plate as described above. A 1 1/2 inch steel roller was placed on the upper plate and centered over the load points. On the rollers were placed blocks one of which allowed a rocking motion under the loading. An I-beam served to transmit the load from the machine to the beam. A fine thread was stretched along the center of one side of the beam and fastened to it directly over the supports, so as to clear the beam about one inch. The def-

lection of the beam past the thread was read on a small scale by the aid of a mirror, which was fastened to the side of the beam by plaster of paris.

The deformation of the upper and lower fibres of the 12 ft. beams were read by means of a Johnson Extensometer, reading to 0.0001 inch. The four contact points of each extensometer yoke were placed in a vertical plane perpendicular to the axis of the beam, and 4 in. inside the load points, thus giving a gage length of 40 inches. The upper points were 1/2 inch below the top of the beam and the lower points 9 1/2 inches below the upper ones. For construction of the extensometer see Fig. 1 on page 14

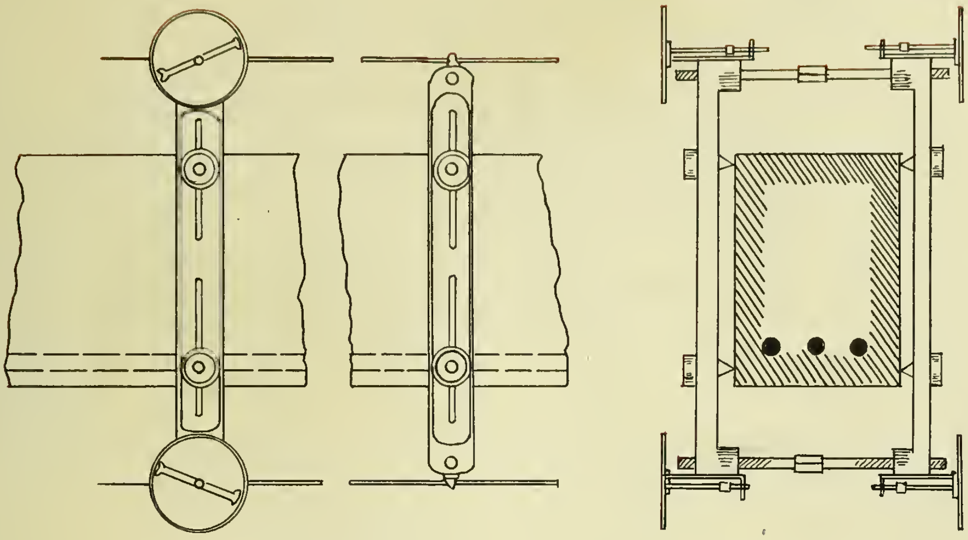
The loads were applied in 2000 pound increments, up to 10000 pounds and then in 1000 pound increments. Readings of the extensometer were taken after the application of each increment of load. As the test progressed the beam was carefully watched to detect the appearance of cracks, their location, and time of appearance. A sketch of the beam was made after failure and the condition of the concrete was carefully noted.

In a few cases the beams were tested by applying a uniform load. The method was as follows; The beams were placed on 38 springs, in pairs, 4 inches apart, that allowed a total closure of 2 inches. By placing the beams with the reinforcing on top, and applying the load at points, which under concentrated loading would be the supporting points, the beams were caused to

bear down on the springs which acted as a uniform load.

Results of tests on 6 inch cubes will be found in Table 6. and of those on control beams in Tables 9,12, and 14.

Fig. 1



Side View End View

Extensometer Device.

TABLE 5.

Tension Tests of Steel Used in Beams.

Specimen Taken from Beam No.	Nominal Size of Steel in Inches	Diameter in Inches	Percent Elongation in 8 Inches.	Yield Point Lb. per Sq. In.	Ultimate Strength Lb. per Sq. In.
3	3/4 in. Round.	.748	29	39,500	64,000
4	3/4 " " .	.747	33	39,300	61,000
5	1/2 " " .	.506	27	37,000	58,600
6	3/4 " " .	.747	31	38,300	64,400
9	1/2 " " .	.507	37.5	37,200	58,200
17	3/4 " " .	.747	30	36,600	58,300
23	3/4 " " .	.750	30	38,500	60,500
29	3/4 " " .	.749	28	36,600	60,400
32	5/8 " " .	.631	31	34,800	56,400
34	5/8 " " .	.623	28	33,800	51,800
36	5/8 " " .	.623	32	35,000	54,000
37	3/4 " " .	.752	31	39,000	62,600
38	3/4 " " .	.750	30	40,300	64,200
40	5/8 " " .	.627	35	34,200	51,200
42	3/4 " " .	.747	30	41,500	64,900
43	5/8 " " .	.624	33	33,300	50,900
45	3/4 " " .	.750	31	37,700	61,800
46	5/8 " " .	.626	34	33,200	51,600
47	3/4 " " .	.752	30	38,700	61,500
49	1/2 " " .	.501	29		
51	5/8 " " .	.627	27	35,300	54,400
56	3/4 " " .	.750	31	39,000	62,900
60	3/4 " " .	.751	35	36,150	57,000
94	1/2 ". Corr. Round.	.500	19	65,800	137,000
96	1/2 ". " . " .	.500	14	68,000	128,000
97	1/2 ". " . " .	.500	15	71,500	136,000
109	1/2 in. Round.	.507	28	37,200	57,500

Table 6

Compression Tests of 6-in. Cubes

Series of 1908

Concrete as in Beam No.	Age when tested days	Compressive Strength lbs. per sq. in.	Concrete as in Beam No.	Age when tested days	Compressive strength lbs. per sq. in.	Concrete as in Beam No.	Age when Tested days	Compressive Strength lbs. per sq. in.
1	69	1980	32	99	1870	64	68	2150
2	67	3155	33	92	2063	71	62	2008
3	70	2160	34	93	2063	73	57	1640
4	70	2170	36	89	1850	80	61	1710
6	69	2390	37	85	2110	81	61	1710
8	69	2390	38	85	2207	82	61	1710
9	87	2775	39	93	1910	83	61	1968
10	88	2517	40	93	1910	87	61	1375
12	86	2410	41	95	2157	88	55	1133
13	88	2775	43	82	2135	90	67	1233
14	85	2787	45	80	1737	92	67	1315
16	92	1923	46	81	1555	94	67	1315
17	91	2187	48	83	1978	95	71	1490
18	91	2187	51	73	2147	96	71	1347
20	87	2140	52	62	2662	97	71	1350
21	87	2100	54	65	2658	98	71	1529
23	87	1887	55	65	2658	100	61	1377
24	101	2590	56	62	2682	101	70	1101
26	99	2103	58	72	1903	102	65	2013.
28	99	1827	60	71	2120			
30	94	2180	61	71	2120			

IV.

EXPERIMENTAL DATA AND DISCUSSION.

-------------0-------------

Explanation of Tables.

Table 7. contains the value of J for beams of 1-2-4 concrete, 60 days of age, and with reinforcement varying from 1% to 3%. J is the ratio of d' to d. J is a value which equals d', the distance from the center of the reinforcement to the center of gravity of the compressive stresses, divided by d.

Tables 8, 11, and 13 give data of the make up of the beams tested and Tables 9, 10, 12 and 14 contain the data of the tests of the beams under Classes A, B and C respectively. Table 15 gives a comparison of the shearing stress in the beams, without web reinforcements with the modulus of rupture of the control beams and crushing strength of cubes.

In the computation of vertical shearing stresses and normal bond stresses 6 pounds was added to the values obtained from the formulae to compensate for the weight of the beams.

TABLE 7.

Values of J.

1 - 2 - 4 concrete.

Reinforcement %.	Age, 60 days.
1.00	0.850
1.24	.840
1.47	.831
1.55	.829
1.60	.827
1.67	.824
1.78	.823
1.88	.822
1.92	.821
2.2	.810

(Con't)

2.8	.800
3.0	.800

CLASS A.

TABLE 8.

DATA ON BEAMS.

1-2-4 Concrete.

Beam No.	Amount of Reinforcement	Percent of Reinforcement	Manner of Failure.
1	4 - $\frac{1}{2}$ in. Plain Round Rods.	1.0	Diagonal Tension
2	4 - $\frac{5}{8}$ " " " " .	1.6	" " .
3	4 - $\frac{3}{4}$ " " " " .	2.2	" " .
4	4 - $\frac{1}{2}$ " " " " .	1.0	" " .
5	7 - $\frac{1}{2}$ " " " " .	1.67	" " .
6	4 - $\frac{3}{4}$ " " " " .	2.2	" " .
7	7 - $\frac{1}{2}$ " " " " .	1.6	" " .
9	7 - $\frac{1}{2}$ " " " " .	1.6	" " .
10	4 - $\frac{1}{2}$ " " " " .	1.55	" " .
11	4 - $\frac{3}{4}$ " Square Cor.	2.8	" " .
14	3 - $\frac{3}{4}$ " Plain Round Rods	1.67	" " .
15	4 - $\frac{1}{2}$ " " " " .	1.0	" " .
16	6 - $\frac{3}{4}$ " " " " .	2.8	" " .
17	4 - $\frac{3}{4}$ " " " " .	2.2	" " .
19	3 - 1 " " " " .	3.0	" " .
20	4 - $\frac{3}{4}$ " " " " .	2.8	" " .
22	3 - $\frac{3}{4}$ " " " " .	1.6	" " .
23	4 - $\frac{3}{4}$ " " " " .	2.2	" " .
25	4 - $\frac{1}{2}$ " Square Cor.	1.55	" " .
29	4 - $\frac{3}{4}$ " Plain Round Rods.	2.2	" " .
30	4 - $\frac{5}{8}$ " " " " .	1.67	" " .
31	4 - $\frac{1}{2}$ " " " " .	1.0	" " .
33	5 - $\frac{1}{2}$ " Square Cor	1.55	" " .
37	3 - $\frac{3}{4}$ " Plain Round Rods	1.6	Tension.
38	4 - $\frac{3}{4}$ " " " " .	2.2	Diagonal Tension.
42	3 - $\frac{3}{4}$ " " " " .	1.6	" " .
43	4 - $\frac{5}{8}$ " " " " .	1.6	" " .
44	4 - $\frac{1}{2}$ " Square Cor.	1.55 ?	" " .
45	4 - $\frac{3}{4}$ " Plain Round Rods	2.2	" " .
49	7 - $\frac{1}{2}$ " " " " .	1.6	" " .
46	4 - $\frac{5}{8}$ " " " " .	1.6	" " .
57	7 - $\frac{1}{2}$ " " " " .	1.6	" " .
60	4 - $\frac{3}{4}$ " " " " .	2.2	" " .
64	4 - $\frac{3}{4}$ " Square Cor.	2.8	" " .
65	4 - $\frac{1}{2}$ " Plain Round Rods	1.0	" " .
73	3 - 1 " " " " .	3.0	" " .
74	4 - $\frac{3}{4}$ " " " " .	2.2	" " .
100	5 - $\frac{1}{2}$ " Round Cor.	1.55	" " .

CLASS A.

TABLE 9

EFFECT OF VARYING AMOUNT OF REINFORCEMENT.

6-FT SPAN 1-2-4 MIXTURE. LOADED AT $\frac{1}{3}$ POINTS.

Beam No.	Per-Cent of Rein.	Age Days	Load at 1st Diagonal Crack Pounds.	Maximum Applied Load. Pounds.	Stress in Longitudinal Reinforcement Lb per Sq. In.	V Shearing Stress Lb. per Sq. In.	Bond Stress Lb per Sq. In.	Control Beam. Modulus of Rupture Lb per Sq. In.	Control Beam. Age Days.
1	1.0	83	15,000	20,000	35,400	153	202		
65		70	16,000	20,000	35,400	153	202		
4		79	17,000	17,500	30,900	135	178	254	80
15		94	20,000	20,500	36,200	150	206		
31		81	14,000	20,000	35,400	153	202		
10	1.55	89	20,000	20,800	24,300	191	198	347	89
25		89	—	20,800	24,300	191	164		
44		72	—	15,700	18,350	146	125		
33		91	16,900	18,400	21,500	169	116	365	82
100		71	—	14,500	17,000	135	117		
2	1.6	84	14,000	16,400	15,900	130	133		
37		80	18,000	18,550	20,400	146	165	280	77
46		71	10,000	11,000	12,500	90	92		79
7		92	21,100	21,500	24,400	169	124		
22		84	—	19,000	21,600	149	169	236	106
42		78	21,000	22,800	25,900	179	201		
43		72	—	17,200	19,500	136	139	289	77
49		77	17,000	20,000	22,700	158	116		
57		66	—	18,200	20,700	144	106		
5	1.67	80	18,200	20,400	22,200	161	118		
14		87	21,000	21,800	23,800	171	192	450	86
30		77	—	18,000	19,650	142	145	368	75
6	2.2	79	—	20,000	16,800	160	136	324	79
17		85	—	20,700	17,400	165	141	425	88
29		77	—	18,700	15,700	150	128		
3		80	—	19,000	16,000	150	130	270	80
38		80	—	16,950	14,200	136	116	330	77
60		65	—	24,700	20,800	196	167		
74		61	—	20,500	17,200	164	140		
16	2.8	95	—	16,000	10,750	131	77	364	89
11		89	21,000	22,000	14,750	178	153		
20		84	—	25,500	17,100	205	173	346	90
64		70	20,000	21,100	14,150	171	146	336	63
19	3.0	84	—	22,000	13,750	178	152		
73		61	14,000	19,800	12,400	161	137	269	55

CLASS A.

TABLE 10

EFFECT OF LENGTH

1 2 – 4 MIXTURE LOAD AT $\frac{1}{3}$ POINTS.

BEAM No.	SPAN FEET	AGE DAYS	LOAD AT 1ST DIAGONAL CRACK. POUNDS.	MAXIMUM APPLIED LOAD POUNDS	STRESS IN LONGITUDINAL REINFORCEMENT LB. PER SQ. IN.	V SHEARING STRESS LB PER SQ IN.	BOND STRESS LB PER SQ. IN.	CONTROL BEAM. MODULUS OF RUPTURE LB. PER SQ IN	CONTROL BEAM. AGE DAYS
6	6	79	—	20,000	16,800	160	136	324	79
17		85	—	20,700	17,400	159	135	425	88
22		84	—	19,000	21,600	150	169	236	106
29		77	—	18,700	15,700	150	128	—	—
43		72	—	17,200	19,500	139	139	289	77
9	9	89	14,000	16,000	27,300	127	94	372	89
23		84	—	20,600	23,950	129	143	400	93
45		71	16,000	18,800	23,750	128	131	196	71
2	12	84	14,000	16,400	31,[illegible]60	130	133	—	—
3		80	—	19,000	32,000	152	130	276	80
16		95	—	16,000	21,400	131	77	364	89
37		80	18,000	18,550	48,800	140	159	280	77
38		80	—	16,950	28,400	136	116	330	77
46		71	10,000	11,000	25,000	90	92	—	—

Table II

Data of Beams with Reinforcing Bars Bent Up

Class B

All Beams 6 ft. Long — 1-2-4 Concrete

Beam Number	Longitudinal Reinforcement		
	Description	Per Cent	Disposition
12	1X3 in. X 6 ft. 3 in Kahn Bar	1.78	6-9 in. prongs at each end. Marked C.
24	Do.	Do.	Prongs Staggered. Bent 50° to Hort.-izontal. Marked B
39	Do.	Do.	Marked A
61	Do.	Do.	Do
81	Do.	Do.	Marked B.
8	6-$\frac{1}{2}$ in round bars	1.47	Two bars bent up, 24 in from ends to points $2\frac{1}{2}$ in from top and 3 in. from ends
13	Do.	Do.	Four bent up as above
18	Do.	Do.	Three bent up as above.
21	Do.	Do	One bent up as above.
80	Do.	Do.	Do.
88	Do.	Do.	Three bars bent up. One bar bent up from a point 1 in. from bottom and 24 in. from end to point 15 in. ~~from~~ from end and $2\frac{1}{2}$ in. from top and then bent parallel to top. Two bars bent up 15 in. from end to $2\frac{1}{2}$ in. from top.
94	6-$\frac{1}{2}$ in. corrugated round bars	1.47	Two bars bent up in same way as those of Beam 8
96	Do.	Do.	Three bars bent up. Same as those in Beam 88
97	Do	Do.	Four bars bent up. Two bars bent up from a point 1 in. from the bottom and 24 in. from the end to point 15 in. from end and $2\frac{1}{2}$ in. from top and then bent parallel to top. Two bars bent up 15 in. from end to $2\frac{1}{2}$ in. from top.
55	6-$\frac{1}{2}$ in. square corrugated bars.	1.88	Two bars bent up. in same way as those of Beam 8
58	Do.	Do.	Three bars bent up in same way as those of Beam 88
71	Do.	Do.	Four bars bent up in same way as those of Beam 97
34	5-$\frac{5}{8}$ in. round bars	1.92	One bar bent up, 24 in. from ends to points 7 in. from top and 3 in. from end.
36	Do.	Do.	One bar bent up in same way as those of Beam 8
40	Do.	Do.	One bar bent in same way as that of Beam 34
48	Do.	Do.	Two bars bent up in same way as those of Beam 8
51	Do.	Do.	Three bars bent up in same way as those of Beam 88. Two bent from same points as one bar of this Beam 88 One as the two bars.
101	Do.	Do.	Three bars bent up same as above.
82	5-$\frac{1}{2}$ in. round bars	1.24	Three bars bent up in same way as those of Beam 8
87	Do.	Do.	Four bars bent up in same way as those of Beam 97.
95	4-$\frac{1}{2}$ in. round bars	1.01	Two bent up in same way as those of Beam 8
41	4-$\frac{1}{2}$ in. square corrugated bars	1.25	One bar bent up same as that in Beam 34.
83	Do.	Do.	Do.

Table 12

Tests of Beams with Reinforcing Bars Bent Up

All Beams failed by Diagonal Tension, except Beam 97, which failed by compression

Beam Number	Age Days	Load at First Diagonal Crack Lb.	Maximum Applied Load Lb.	Stress in Longitudinal Reinforcement Lb. per Sq. in.	Nominal Vertical Bond Stress Lb. per Sq. in.	Nominal Vertical Shearing Stress Lb. per Sq. in.	Control Beam	
							Modulus of Rupture Lb. per Sq. in.	Age Days
12	89	19100	25700	26600	183	201	578	88
24	89	18000	32700	33600	238	254	475	91
39	79	25000	31000	32000	220	251	410	76
61	65	18000	26100	26900	186	204	266	58
81	64	25000	32300	33300	228	250	256	69
8	90	—	23800	29100	157	185	–	–
13	89	27000	35300	43200	229	271	386	88
18	88	19100	25000	30600	164	194	—	—
21	84	20000	22800	27400	150	177	367	93
80	72	20000	20100	24500	133	157	256	69
88	68	14000	14300	17500	97	114	127	76
94	72	11000	14300	17500	97	114	175	97
96	72	21000	25500	31300	167	198	127	97
97	72	19000	25300	31000	166	196	127	97
55	65	18000	34100	33200	180	266	–	–
58	61	25000	43100	42400	225	333	266	58
71	62	31000	36400	44600	140	285	300	61
34	80	18000	18200	17300	118	145	340	81
36	81	–	21200	19600	137	168	340	81
40	78	17000	17100	16400	112	136	270	76
48	80	–	20900	19500	135	166	219	69
51	69	21000	23000	21900	148	171	219	69
101	71	19000	21100	19600	136	165	182	96
82	72	23000	30000	36800	196	232	296	69
87	71	15000	19700	24900	131	153	127	76
95	72	13000	14300	24700	141	106	175	97
41	79	17000	20100	24000	156	155	270	76
83	72	20000	26700	32000	205	205	296	69

Table 13.

Data of Beams with Stirrups

Class C.

All Beams 6 ft. long. 1-2-4 Concrete.

Beam Number	Amount of Longitudinal Reinforcement	Per cent of Londitudinal Reinforcement	Amount of Stirrups
26	3 - $\frac{3}{4}$ in. Round	1.66	$\frac{1}{4}$ in Corr. mild steel Sq. bars 3 in spacing
27	5 - $\frac{1}{2}$ in Corr. Sq. bars.	1.56	$\frac{1}{2}$ in corrugated Rd. bars 5 in. spacing
* 28	4 - $\frac{3}{4}$ in Corr. Sq. bars	2.80	$\frac{1}{2}$ in corrugated Sq. bars 6 in. spacing.
32	4 - $\frac{5}{8}$ in plain Rd. bars.	1.54	$\frac{1}{2}$ in corrugated Sq. bars 4 in. spacing
50	4 - $\frac{5}{8}$ in. plain Rd. bars 2 bent up.	1.54	$\frac{1}{2}$ in corrugated Sq. bars 6 in spacing
52	3 - $\frac{3}{4}$ in. plain Rd. bars	1.66	wire mesh. 4 in. spacing.
53	4 - $\frac{5}{8}$ in. plain Rd. bars	1.54	$\frac{1}{2}$ in plain Round bars 4 in. spacing
54	3 - $\frac{3}{4}$ in. plain Rd. bars	1.66	$\frac{1}{4}$ in corrugated Sq. bars 4 in. spacing
56	do.	1.66	$\frac{1}{4}$ in. Corr. mild steel Sq. bars. 2 in spacing.
59	do.	1.66	$\frac{1}{4}$ in. Corr. mild steel Sq. bars. 3 in. spacing.
89	4 - $\frac{5}{8}$ in. plain Rd. bars.	1.54	$\frac{1}{2}$ in corrugated Sq. bars 4 in. spacing.
90	5 - $\frac{1}{2}$ in Corr. Rd. bars.	1.24	$\frac{1}{2}$ in. corrugated Rd. bars. 5 in. spacing.
91	4 - $\frac{5}{8}$ in plain Rd. bars	1.54	$\frac{1}{2}$ in. plain Rd. bars 4 in. spacing.
92	4 $\frac{5}{8}$ in plain Rd. bars 2 bent up.	1.54	$\frac{1}{2}$ in plain Round bars 5 in. spacing.
93	5 - $\frac{1}{2}$ in. Corr. Rd. bars 2 bent up.	1.24	$\frac{1}{2}$ in corrugated Sq. bars 6 in spacing.
98	4 - $\frac{5}{8}$ in plain Rd. bars	1.54	$\frac{1}{4}$ in. Corr. mild steel Sq. bars 4 in. spacing.
99	do.	1.54	$\frac{1}{2}$ in. plain Round bars 6 in. spacing.
102	4 - $\frac{5}{8}$ in plain Rd. bars 2 bent up.	1.54	$\frac{1}{2}$ in plain Round bars 5 in spacing.
103	3 - $\frac{3}{4}$ in. plain Rd. bars	1.66	$\frac{1}{4}$ in. Corr. mild steel Sq. bars 4 in. spacing.
104	do.	1.66	$\frac{1}{4}$ in Corr. mild steel Sq. bars 2 in. spacing
106	5 - $\frac{1}{2}$ in Corr. Rd. bars.	1.24	$\frac{1}{2}$ in corrugated Sq. bars 5 in. spacing.
107	do	1.24	$\frac{1}{2}$ in corrugated Sq. bars. 6 in. spacing
108	4 - $\frac{5}{8}$ in plain Rd. bars 2 bent up.	1.54	$\frac{1}{2}$ in. plain Round bars 5 in. spacing.

Notice * 12 ft. Long.

Table 14.

Test of Beams with Stirrups

Class C. 1-2-4 Concrete.

All Beams 8x10 in x 6 ft. long except No 28 which 12 ft.

Beam No.	Age days	Load at First Diag. crack Pounds.	Maximum Applied Load lbs.	Stress in Long. Reinf. lbs. per Sq. in.	Nominal Vertical Shearing Stress lbs. per sq. in.	Nominal Bond Stress lbs. per Sq. in.	Tensile Stress in Stirrups lbs. per Sq. in.	Bond in Stirrup lbs. Per Sq. in.	Manner of Failure	Control Beam	
										Modulus of Rupture lbs. per Sq. in.	Age days.
one third point Loading											
26	86	19000	19200	20700	144	164	28000	292	Diag. Tension	319	86
27	87	26000	29300	34000	220	176	23300	485	do.	—	—
28	87	16000	21300	28500	166	111	16000	334	Compression of Concrete	322	86
32	81	—	16300	19600	122	126	7840	163	diag. tension	288	80
* 50	70	24000	27000	32000	203	207	12500	131	do.	218	69
52	59	24000	26400	29000	200	225	—	—	do	356	58
53	59	17000	23800	27600	179	172	14600	304	do	—	—
54	59	—	25000	27500	190	214	48500	505	do	310	63
56	65	17000	25300	27800	192	216	24600	256	do	414	63
59	66	—	19200	21000	146	163	27900	293	do	—	—
89	67	13000	18300	22000	138	141	8900	184	do	—	—
90	67	19000	23900	34100	178	181	18200	356	do	154	77
91	67	—	16300	19600	122	126	10000	209	diag. tension slip of bar	—	—
* 92	67	13000	14200	16800	107	109	5400	57	do	155	77
* 93	75	18000	24100	34500	178	182	10900	113	slip of stirrups	—	—
* 102	65	25000	26100	30900	196	200	10000	105	diag. tension	316	67
103	68	18300	25300	27800	193	200	49100	510	do	—	—
104	68	27000	30200	33100	230	238	29100	304	do	275	67
106	64	20000	22700	32500	169	172	18100	359	do	260	66
* 107	64	36000	40100	57500	296	302	18200	189	compression of concrete	—	—
* 108	64	25000	25500	31100	191	193	9750	102	diag. tension	300	66
Uniform Loading.											
98	71	—	30000	26500	226	230	58000	600	tension of stirrup.	198	71
99	71	—	30500	26600	230	234	28000	570	diag tens.	—	—

* Part of Bars in these beams were bent up outside the load point. See sketches of beams for details.

CLASS A.

TABLE 15.

RATIO OF V. SHEARING STRESS TO MODULUS OF RUPTURE AND COMPRESSIVE STRESS

1-2-4 MIXTURE.

BEAM No.	V SHEARING STRESS LB. PER SQ. IN.	MODULUS OF RUPTURE OF CONTROL BEAM LB. PER SQ. IN.	RATIO PERCENT.	CRUSHING STRENGTH OF 6 IN. CUBES LB. PER SQ. IN.	RATIO PERCENT.
1	147	—	—	1980	7.4
3	146	270	54	2160	6.8
4	129	254	51	2170	5.9
6	154	324	47	2390	6.5
9	121	372	33	2775	4.3
10	185	347	54	2517	7.3
14	165	450	37	2787	5.9
16	125	364	34	1923	6.5
17	159	425	37	2187	7.3
20	199	346	57	2140	9.3
22	144	236	61	—	—
23	133	400	33	1887	7.1
30	136	368	37	2180	6.3
33	163	365	45	2063	7.9
37	140	280	50	2110	6.7
38	130	330	40	2207	5.8
43	130	289	45	2135	6.1
45	122	196	62	1737	7.0
46	84	—	—	1555	5.4
64	165	336	49	2150	7.7
73	155	269	57	1640	9.5

Following are descriptions of the tests of the beams in each class.

Class A.

As these beams did not have web reinforcement and nearly all of them failed suddenly along one distinct crack, a "Log" of the tests will not be given.

Class B.

Beam. 8.

The first vertical crack was noticed at 20 000 lb. It appeared 12 in. outside of south load point. At 22 000 lb. a vertical crack appeared 4 in. outside of north load. The beam failed at 23800 lb. along a diagonal crack which extended from the north support to a point in the top of the beam 3 in. outside of north load point. The failure was sudden.

Beam. 12.

This beam was reinforced with a Kahn bar. At 19100 lb. a vertical crack appeared 2 in. north of north load point along with a diagonal crack which began at the bottom of the beam 10 in. outside of the south load point and extended about 5 in. high and 2 in. south of the south load point. A vertical crack appeared 4 in. south of the center of the beam

at 20100 lb., another one appeared at 21000 lb. 8 in. north of the north load point, and vertical cracks were also noticed under the north and south load points. At 25000 lb. a vertical crack appeared 6 in. south of the south load point. The beam failed suddenly at 25700 lb. along a diagonal crack which extended from the south support to a point 13 in. outside of the south load on top of the beam. Upon the investigation of the reinforcing bars it was found that, in a few places, concrete was clinging to the bottom of the straight bars, thus strengthening the idea that the straight bar does not slide. The prongs of the reinforcing bars also had concrete on their surfaces.

Beam. 13.

A vertical crack 1 in. high appeared at 21000 lb. 11 in. north of north load point. At 23000 lb. the above crack lengthened to 3 in. Another vertical crack appeared 8 in.north of the south support. The first vertical crack lengthened to 4 in. at 26000 lb.10 in. south of the south load point, a vertical crack appeared at 27000 lb. A diagonal crack extended from the north support to 12 in. outside of the north load point. At 30000 lb. the above diagonal crack had spread to the north load point, at 32000 lb. a vertical crack appeared 7 in. south of the center of the beam. A vertical crack appeared under the south load 1 in. north of north load point. Another vertical crack appeared. Failure occurred at 35300lb. along a diagonal crack which extended from the south support to a point in the top of

beam 13 in. outside of the south load point. A vertical crack 3 in. high appeared at a load of 18000 lb. 1 in. south of the south load; 12 in. north of the south support a diagonal crack appeared at 19100 lb. A diagonal crack was noticed at 25000 lb. 6 in south of the north support and extending to a point at the top of the beam 3 in. north of the north load point, this was the crack at which failure took place. The maximum load was 25000 lb.

Beam. 21.

A diagonal crack appeared 13 in. north of the north load point at 20000 lb. Failure tookplace suddenly at 22800 lb. along a diagonal crack which extended from the south support to a point in the top , 2 in. south of the south load point.

Beam. 24.

This beam was reinforced with a 1 in. x 3 in. Kahn bar. A vertical crack appeared at 18000 lb., 7 in. south of the south load point. A vertical crack 7 in. north of center of the beam also appeared. At 21000 lb. two vertical cracks appeared, one 4 in. inside of the north load point the other 9 in. outside of the north load point. At 23000 lb. a noticable increase in the above cracks took place. At 30000 lb. the first and third of the above described cracks had grown to be 8 in. in length and changed to a diagonal direction. The beam failed at 32700 lb. along a new diagonal crack which extended from the south support to the south load point. The failure was sudden.

Beam. 34.

The beam failed suddenly without any crack appearing before failure. 18000 lb. was the ultimate load. The failure crack was diagonal and extended from the north load point to the north support.

Beam. 36.

A vertical crack appeared 2 in. north of the north load point at 19000 lb. Another appeared 12 in. north of the north load point at 20000 lb. Failure took place along a diagonal crack which extended from the north load point to the north support, at 21200 lb.

Beam. 39.

This beam was reinforced with a 1 in. x 3 in. Kahn bar. No crack appeared until 25000 lb. At this point a diagonal and a vertical crack was noticed. The former was 16 in. inside of the north support and the latter was 17 in. inside the south support. The beam failed at 31000 lb. along a diagonal crack which extended from a point in the top of beam 6 in. north of the north load point to the north support.

Beam. 40.

This beam broke suddenly along a diagonal crack which extended from the south load point to a point one in. from the bottom and 10 in. inside of the south support. The crack continued horizontally along the straight reinforcement to the south support. The breaking load was 17100 lb.

Beam. 41.

The first diagonal crack appeared 10 in. south of the south load point at 17000 lb. The failure was at 20100 lb. along a diagonal crack which extended from the north load point to the north support.

Beam. 48.

This beam failed suddenly at 21900 lb. along a diagonal crack which extended from the load point to the support.

Beam. 51.

This beam failed at 23000 lb. along two diagonal cracks. One extended from a point in the top of the beam 9 in. outside of the north load point to a point in the bottom of the beam 9 in. inside of the south support. The other extended from a point in the top of beam 9 in. inside of the north support to north support. This latter crack was first noticed at 21000 lb.

Beam. 55.

A diagonal crack appeared at a load of 18000 lb. 5 in. north from south support. At 23000 lb. a vertical crack appeared 8 in. inside of the north support. At 26000 lb. vertical crack appeared 10 in. south of the south load point. At 34100 lb. failure took place along a crack which extended from the north load point to a point 1 in. from the bottom and 6 in. inside of the north support. It continued along the straight reinforcement to the north support.

Beam. 58.

This was the strongest beam. It failed at 43100 lb. along a diagonal crack which extended from a point in the bottom of the beam 3 in. inside of the south support. Two diagonal cracks appeared at 23000 lb. and 24000 lb., one 5 in. south of the south load point, the other 8 in. inside of the north support. A vertical crack appeared at 25000 lb. under the north load point and at 26000 lb. a diagonal crack 8 in. inside of the south support. The failure crack appeared at 36000 lb. and grew gradually until failure.

Beam. 61.

This is another beam reinforced with 1 in. x 3 in. Kahn bar. Hair cracks appeared in the bottom at 10000 lb. The first vertical crack took place at 21000 lb. 10 in. north of the north load, another at the s ame load appeared 6 in. south of the center. At 23000, lb. all of the above cracks had grown to larger ones. Failure took place suddenly along a diagonal crack which extended from the sputh load point to the south support. The breaking load was 26800 lb.

Beam. 71.

The first vertical crack appeared at 27000 lb. 2 in. south of the center. At 30000 lb. a vertical crack 11 in. south of the north load point was noticed. At 31000 lb. a diagonal crack appeared 8 in. inside of the south support. At 34000 lb. a diagonal

crack developed at north support nd one 2 in. inside of the south support. Failure took place at 36400 lb. along a diagonal crack which extended from the north load point to the north support.

Beam. 80.

At 15000 lb. a vertical crack appeared under the north load point. At 17000 lb. a vertical crack was noticed under the south load point. At 19000 lb. a vertical crack took place 6 in. north of the center of the beam. At 20000 lb. a diagonal crack appeared 1 in. north of the north load point. The beam failed at 20100 lb. along a diagonal crack which extended from the north load point to the south support.

Beam. 81.

A vertical crack appeared at 22200 lb. 5 in. outside of the north load point. A diagonal crack 8 in. outside of the south load point also appeared under this loading. At 25000 lb. a vertical crack appeared 3 in. north of the center of the beam. A vertical under the north load point appeared at 29600 lb. At 33300lb. the beam failed along the above diagonal crack. It was reinforced with a 1 in. x 3 in. Kahn bar.

Beam. 82.

A vertical crack appeared at 13000 lb. under the north load point. A vertical crack 6 in. south of the south load point appeared at 13000 lb. At 18000 lb. a vertical crack

appeared 6 in. north of the north load point. A load 25000 lb. brought out a diagonal crack 14 in. north of the north load point. A diagonal crack appeared 7 in. north of the north load point. A vertical crack appeared [illegible] in. south of the south load point at 26000 lb. Failure took place at 30000 lb. along a diagonal crack which extended from the south load point to a point in the bottom of the beam 14 in. inside of the north support.

Beam. 83.

A vertical crack appeared at 12000 lb. 4 in. north of the north load point. At a load of 20000 lb. a diagonal crack was noticed 14 in. north of the north load point. A vertical crack under the south load point appeared at 24000 lb. A diagonal crack was noticed at a load of 25000 lb. under the south load point. The beam failed at 26700 lb. along a diagonal crack which extended from the north load point to the north support.

Beam. 87.

The first crack noticed was diagonal, it appeared 6 in. north of the north load point. At 18000 lb. a diagonal crack 12 in. north of the north load appeared. The beam failed at a load of 19700 lb. along a diagonal crack, which extended from the south load point to a [illegible] point, 3 in. from top of beam and 3 in. outside of south load point.

Beam. 88.

Upon testing with a hammer the concrete in this beam seemed extraordinarily poor. A diagonal crack appeared at

14000 lb. 9 in. south of the north load point. Failure took place at 14300 lb. along a diagonal crack which extended from a point in the top of the beam 8 in. outside of the load point to the south support.

Beam. 95.

A diagonal crack appeared 8 in. north of the north support at a load of 13000 lb. Another was noticed at 14000 lb. 6 in. north of the south support. Failure took place at 14300 lb. along a diagonal crack which extended from the north load point to a point 1 in. from the bottom of the beam and 6 in. inside of the north support. The crack continued along the straight reinforcement to the north support.

Beam 96.

The first crack appeared at 13000 lb. It was vertical and 4 in. north of the center of the beam. At 21000 lb. a diagonal crack appeared at the north end. At 23000 lb. diagonal crack appeared at the south support. At 24000 lb. these cracks opened and extended toward the load points. Failure took place at 25500 lb. at both ends along cracks extending from the support to the load points.

Beam. 97.

This is an interesting beam because it is the only one which failed by compression of the concrete. The concrete seemed to be of a poor quality. A diagonal crack appeared at 20000 lb. 4 in. south of the south support. It failed by the crumbling of

the concrete in the center at 25000 lb.

Beam. 101.

A diagonal crack appeared 10 in. north of the north load at 19000 lb. A diagonal crack appeared at the south support. Failure took place along a diagonal crack which extended from the south support to a point in the beam 8 in. from the top and 8 in. outside of the south load point. The ultimate load was 21100 lb.

Class C.

It seems evident from the tests that the stirrups did not take much stress until after the formation of the diagonal cracks. The diagonal cracks appeared on the face of the beams at loads giving the same vertical stress v as those at which the cracks appear in beams of the same span, reinforcement, and quality of concrete not having web reinforcement, or at loads somewhat greater because the vertical shearing stress is carried by web reinforcement. It seems evident that there is very little elongation in stirrups until the first diagonal crack appears, and up to the point the concrete takes all the diagonal tension. After the cracks become visible, the stirrups take the vertical tensile stresses, and the diagonal cracks gradually extend. A peculiarity of the tests of beams with stirrups is slow failure, the beams carrying the load well up to the maximum with increased deflections.

The manner of failure in most cases was diagonal tension of concrete; in a number of cases, the stirrups slipped; in others the steel in the stirrups stressed beyond the elastic limit. In some of the tests failure was by tension in the longitudinal reinforcement, and in some cases the stirrups broke. Two beams No. 28 and 107 failed by compression in the concrete. The following are brief notes of the tests. The location of the cracks is shown in sketches on pages 53 to 57. The heavy lines indicate cracks along which failure took place. Reference

may be made to Tables 13 and 14 for data on the make-up and tests of the beams of Class C.

Beam 26.

A diagonal crack marked(1) was noted on both sides of beam at 19000 lb. at 1 in. to the left of the right support. No cracks were noted at the left end of the beam. Failure was rather sudden and was due to the diagonal tension. The fifth and sixth stirrups from the right end were found to have slipped about 1/8 in. The stirrups were not well embedded, especially at the right end where failure occurred at a maximum load of 19200 lb.

Beam 27.

At 26000 lb. a vertical crack, 5 in. high marked (1) was noted at the center of the beam, a diagonal crack marked (1) 9 in. to right of the left support and also a diagonal crack marked (2) was observed at 14 in. to left of the right support. The last diagonal crack gradually extended and at 29300 lb., maximum load, the beam failed by diagonal tension. The lower part of the stirrups on each side were exposed, and the stirrups slipped a little but the surfaces of the beam were fairly smooth.

Beam 32.

At a maximum load of 16300 lb. a diagonal crack extended from the left support toward the first stirrup from the end. The bars slipped after the diagonal tension failure occurred. The stirrups were slightly exposed at the bottom.

Beam No. 52.

At 15000 lb. a small vertical crack 1 1/2 in. high marked (1) was noted 1 in. to the right of the center of the beam. At 16000 lb. two small vertical cracks, marked (2) appeared 6 in. under the fifth stirrup and also 2 in. to the left from the center of the beam. At 18000 lb. a small vertical crack marked (3) appeared under the sixth stirrup, at 24000 lb. and 25000 lb. diagonal cracks marked (4) and (5) were noted at 10 in. to the right of right load and 1 ft. to the right of the left support respectively. At 26400 lb. maximum load, the beam failed rather suddenly by diagonal tension.

Beam No. 53.

At 17000 lb. a diagonal crack was noted at 6 in. to the right of the right load and at 20000 lb. this diagonal crack extended. The maximum load was 23800 lb. Failure was gradual, by diagonal tension.

Beam No. 54.

At 15000 lb. and 18000 lb. two very small cracks were noted at the bottom of the beam 1 in. and 3 in. to the right of the right load respectively. At 20000 lb. a vertical crack marked (3) appeared 6 in. to the left of the center of the beam. At 21000 lb. and 22000 lb. three small cracks were noted at the bottom of the beam, also a vertical crack marked(4) appeared along the stirrup at the left end. At 24000 lb. a large diagonal crack was noted and it enlarged rapidly. 25000 lb. was the

maximum load. Failure was by diagonal tension at the right end.

Beam No. 56.

At 17000 lb. a small vertical crack marked (1) was noted along the stirrup, at 19000 lb. crack (2) was noted, at 20000 lb. crack (3) and at 24000 lb. cracks (4) and (5). The latter enlarged very rapidly at 25000 lb. 25300 lb. was the maximum load. Failure was by diagonal tension at the left end. The sides of the beam were very rough and one longitudinal bar and all stirrups were exposed.

Beam No. 59.

At 8000 lb. two small cracks marked (1) were noted under the north load and 12 in. to the right of the right load. At 10000 lb. two small cracks marked (2) appeared at the bottom of beam. At 14000 lb. a vertical crack marked (3) and at 15000 lb. a vertical crack marked (4) were noted 5 in. and 3 in. to the left of the left load respectively, these vertical cracks remained the same size until failure occurred. At 19000 lb. large diagonal crack was noted 6 in. to the left of the right support and extended very rapidly. At 19200 lb. the beam failed by diagonal tension. The concrete around the first and second stirrups to the left of the right end was very lean. The lower part of the 5 stirrups were exposed.

Beam No. 89.

At 13000 lb. a small vertical crack marked (1) was noted 8 in. to the right of the right load, at 14000 lb. a vertical crack marked (2) appeared at 3in. to the left of the center

and a diagonal crack marked (3) was noted 4 in. to the left of the left load. At 18300 lb. maximum load failure was by diagonal tension at the left end. In this beam only two stirrups were spaced in each end and one stirrup was spaced 10 in from the support, therefore the stirrups did not take much shear in the end of the beam.

Beam No. 90.

At 15000 lb. a small vertical crack marked (1) was noted along the second stirrup at the left end and at 16000 lb. a vertical crack marked (2) appeared along the stirrups at the symmetrical position in the right end of the beam. At 19000 lb. a diagonal crack marked (3) was noted 8 in. to the left of the right support. At 20000 lb. the first vertical crack changed to a diagonal and this crack helped the final failure of the beam. At 22000 lb. a diagonal crack marked (5) was noted 15 in. to the left of the right support. At 23900 lb. maximum load the beam failed by diagonal tension at the left end and reinforceing bars were stressed to nearly the elastic limit of 34000 lb. per sq. in.

Beam No. 91.

At 13000 lb. a diagonal crack marked (1) was noted along the stirrup at the left end also a vertical crack marked (2). At 14000 lb. a vertical crack (3) appeared. At 15000 lb. cracks (4) and (5) were noted and during consecutive loading the first diagonal crack extended to first stirrup horizontally through the reinforcing bars. At 16300 lb., maximumload, the beam failed by

diagonal tension also due to the slipping of the bar. The concrete was mixed very poorly.

Beam No. 92.

At 12000 lb. the two vertical cracks marked (1) were noted at the right end along the stirrups. At 13000 lb. a diagonal crack appeared 8 in. to the left of the left load. At 14200 lb. the beam failed suddenly by diagonal tension, the bars also slipped slightly. The beam was made very poorly.

Beam No. 93.

At 18000 lb. a vertical crack marked (1) and a diagonal crack marked (2) were noted at the right end of the beam. At 20000 lb. three vertical cracks, and at 22000 lb. one vertical crack appeared near the middle of the beam. At 26000 lb. one vertical crack was noted along the stirrup at the left end of the beam. At 24100 lb., maximum load, failure took place by the slipping of the two end stirrups in the right end.

Beam No. 106.

At 19000 lb. a vertical crack marked (1) was noted 10 in. to the right of the left support a diagonal crack started at 20000 lb. at 21000 lb. the first crack turned into a diagonal crack. At 22000 lb. another diagonal crack started at the same end. At 22700 lb., the maximum load, failed took place by diagonal tension. The sides were smooth and no stirrups were exposed.

Beam No. 107.

At 16000 lb. a very small vertical crack marked (1) was noted 4 in. to the right of the center, this crack remained until failure occurred. At 31000 lb. and 32000 lb. two vertical cracks were noted. At 34000 a vertical crack started at the stirrup at the left end of the beam. At 35000 lb. a vertical crack was noted at the same end of the beam. At 36000 lb. two diagonal cracks 10 in. and 15 in. to the right of the left support appeared. At 37000 lb. a diagonal crack was noted 9 in. to the left of the right support at stirrups. At 39000 lb. a diagonal crack appeared 2 in. to the right of the left support. All of the above diagonal cracks started at the stirrups. The maximum load was 41000 lb. Failure was by compression of concrete at the center of the beam. The concrete seemed of good quality. The diagonal cracks on the side, were very narrow. Tensile stress in the longitudinal bar was 57500 lb., nearly the elastic limit of the corrugated bar.

Beam No. 102.

At 20000 lb. a small vertical crack marked (1) was noted along the stirrup at the right end of the beam and two cracks developed to diagonal cracks at 25000 lb. as shown in (2). At 26000 lb. two diagonal cracks marked (3) were noted 6 in. and 12 in. to the left of the right support. The maximum load was 26000 lb. The above diagonal crack extended rapidly and the beam failed by diagonal tension. In the beam both faces

were rough and the lower part of all the stirrups were exposed.

Beam No. 103.

At 15500 lb. a vertical crack marked (1) was noted along the stirrups and at 18000 lb. a vertical and a diagonal crack appeared as shown. At 23000 lb. the second vertical crack extended gradually and changed into a diagonal crack. At 24000 lb. a vertical crack marked (4) was noted 4 in. to the left from the center of the beam. At 25300 lb. the beam failed suddenly by diagonal tension as shown in the figure. In this case the tensile stress in the stirrups was 49000 lb. No stirrups were exposed.

Beam No. 104.

At 27000 lb. a diagonal crack started at the right end as shown, and at 28000 lb. a crack marked (2) was noted at the left support. This crack extended rapidly at the succeeding load. Failure was sudden and by diagonal tension, the maximum load was 30200 lb. The sides of the beam were rough but no stirrups were exposed.

Beam No. 108.

At 18000 lb. a vertical crack marked (1) was noted at the center of the beam. At 20000 lb. and 21000 lb. two vertical cracks were noted symmetrically near the center of the beam as shown. At 25000 lb. a vertical crack marked (4) started along the stirrup. At 25500 lb. the maximum load, the beam failed suddenly by diagonal tension.

Beam No. 28.

At 12000 lb. and 13000 lb. two vertical cracks marked (1) and (2) were noted at both ends of the beam. At 16000 lb. one diagonal and three vertical cracks marked (3) were noted at the foot of the stirrups. At 19000 lb. vertical crack marked (4) was noted near the center. At 20000 lb. diagonal crack marked (6) was noted, and at 21000 lb. another diagonal crack appeared at the symmetrical position. The maximum applied load was 21300 lb. The beam failed by compression in the center as shown. It seemed the concrete was mixed very poorly. The sides of the beam were rough and the lower parts of most of the stirrups were exposed.

Beam No. 98. Uniform Loading.

At 20000 lb. a crack marked (1) was noted at 3 in. to the left of the center, At 24000 lb. and 26000 lb. four cracks marked (2), (3), (4), and (5) were noted as shown. All the above cracks were very small and only appeared on the top of the beam. A number of cracks were noted at the side of the beam. The maximum load was 30000 lb. Failure was sudden , one stirrup broke and slid along the concrete at the top. But it is very curious that stress in the stirrups of 58000 lb. was developed The springs compressed about 1 1/4 in.

Beam No. 99.

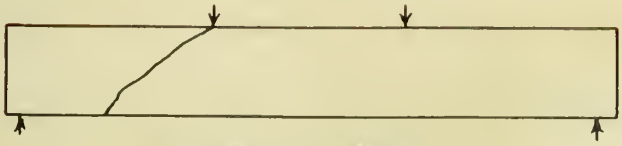
At 18000 lb. a small crack marked (1) was noted at the center. At 22000 lb. a crack appeared marked (2) noted as shown. At 26000 lb. two cracks marked (3) and (4) also at

28000 lb. a crack marked (5) were noted as shown. All of the above cracks were noted at the top of the beam. A number of cracks appeared at the side. The maximum load was 30500 lb. Failure was sudden by diagonal tension between the stirrups. The sides of the beam were smooth, no stirrups were exposed.

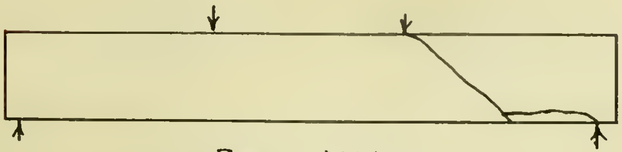
Beam No. 50.

At 12000 lb. a vertical crack marked (1) was noted at 3 in. to the right of the right load. At 14000 lb. two vertical cracks marked (2) were noted as shown. At 15000 lb. two vertical cracks marked (3) were also noted at the left end of the beam. At 17000 lb. a small vertical crack marked (4) appeared near the center of the beam. At 24000 lb. two diagonal cracks marked (5) were noted at the symmetrical positions as shown. The maximum load was 27050 lb. Failure was by diagonal tension. Two stirrups at the end slipped. The surface of the beam was very rough and the lower part of the west stirrup was exposed.

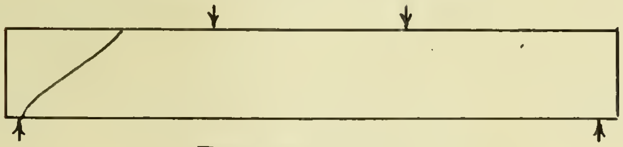
Beams of 6'-0" Span.



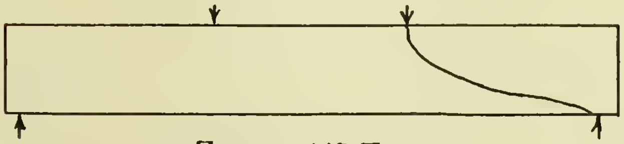
Beam No. 1.
No. 4 Similar.



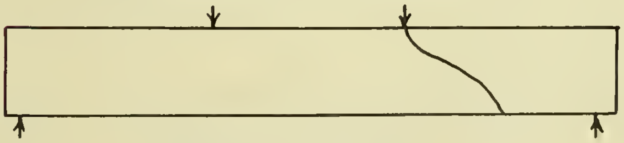
Beam No. 5.
Nos. 29 and 60 Similar.



Beam No. 6.

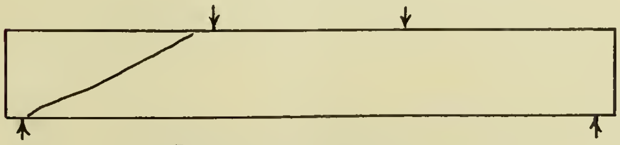


Beam No. 7.
Nos. 10, 11, 15, 25, 64 and 100 Similar.

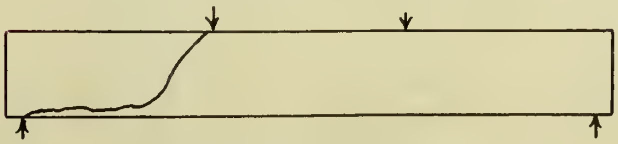


Beam No. 14.
No. 31 Similar.

Beam No. 17.
Nos. 19, 20, 33, 42, 43, 44, 49, 65, 73 and 74 Similar.

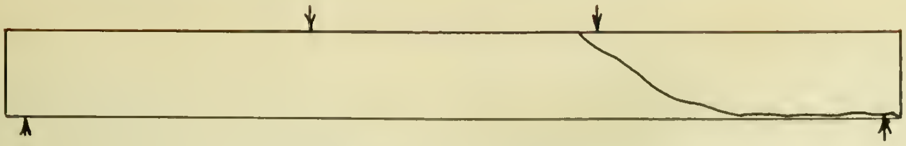


Beam No. 22.
Nos. 30 Similar.

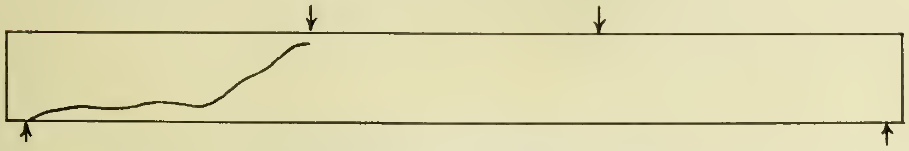


Beam No. 57.

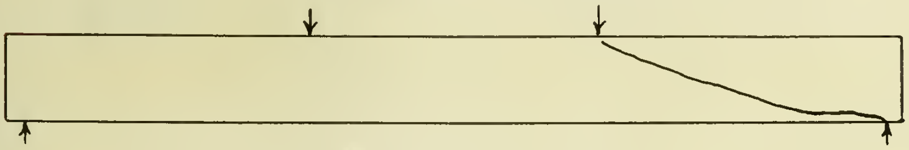
BEAMS OF 9'-0" SPAN.



BEAM No. 9.

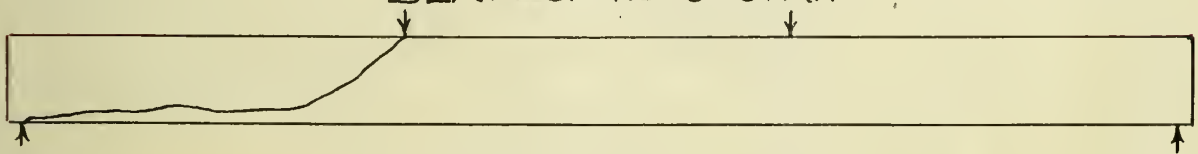


BEAM No. 23.

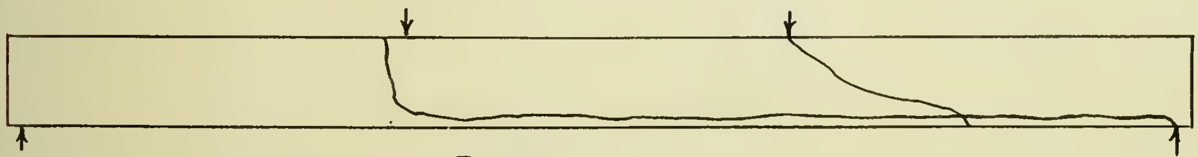


BEAM No. 45.

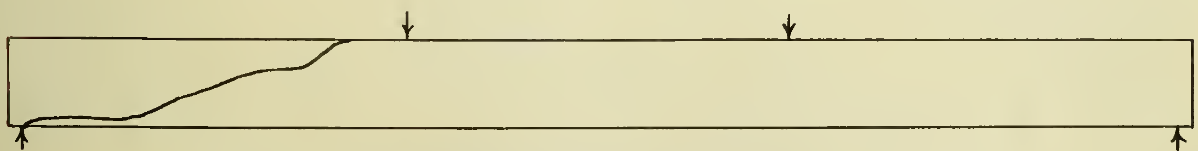
BEAMS OF 12'-0" SPAN.



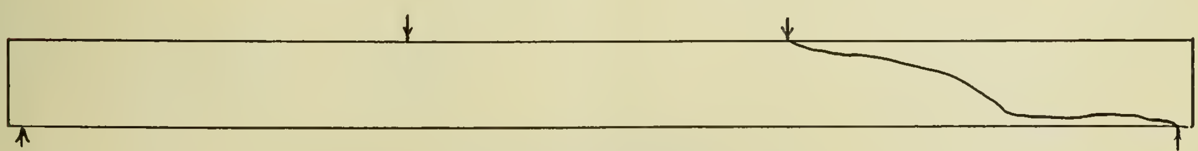
BEAM No. 2.
BEAM No. 3, SIMILAR.



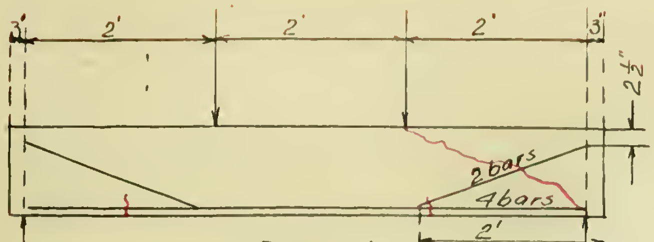
BEAM No. 16.



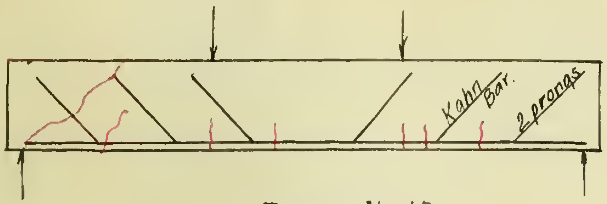
BEAM No. 37.
BEAM No. 38 SIMILAR.



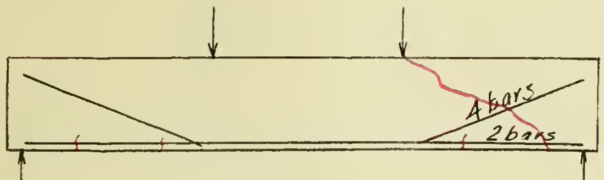
BEAM No. 46.



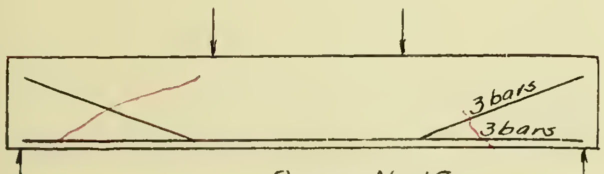
Beam No. 8



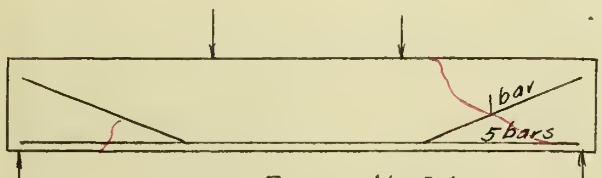
Beam No. 12



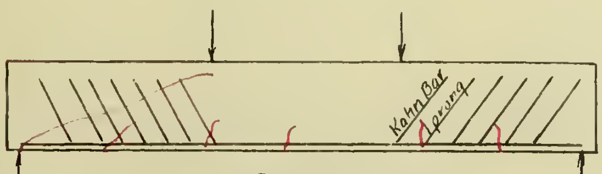
Beam No. 13



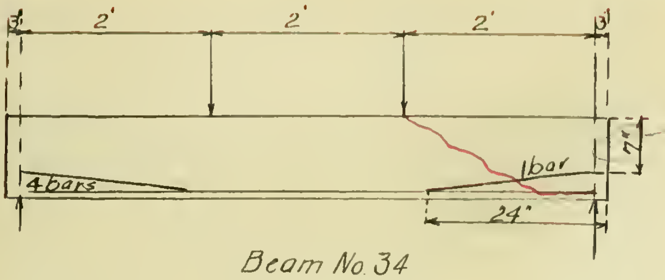
Beam No. 18



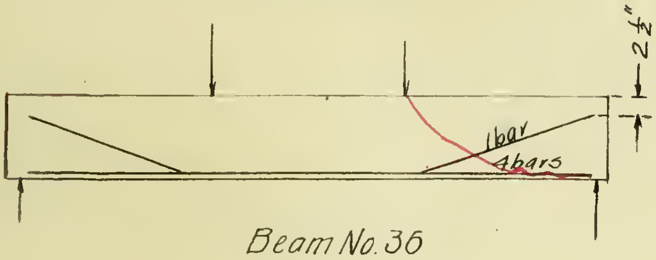
Beam No. 21



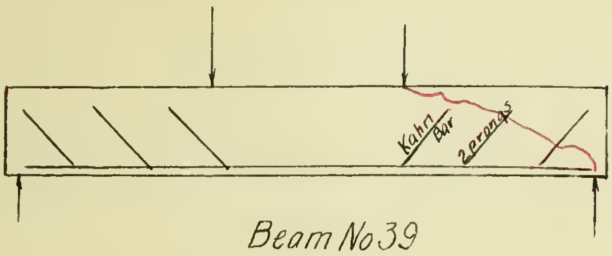
Beam No. 24



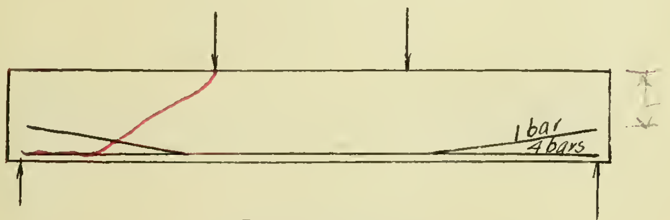
Beam No. 34



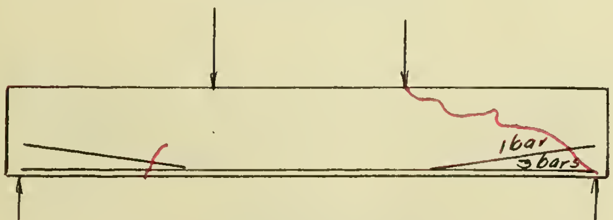
Beam No. 36



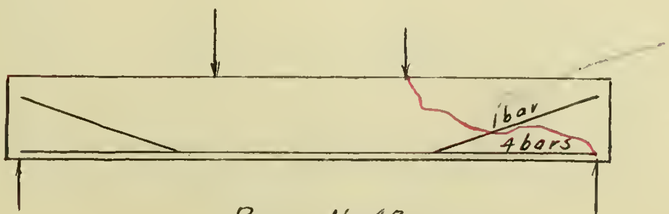
Beam No 39



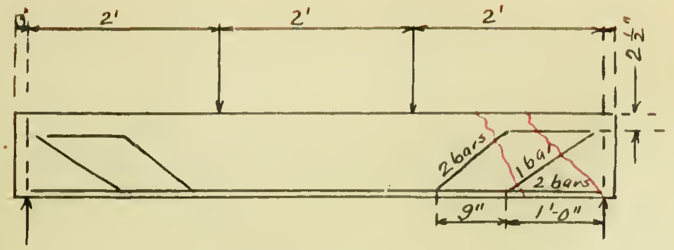
Beam No. 40



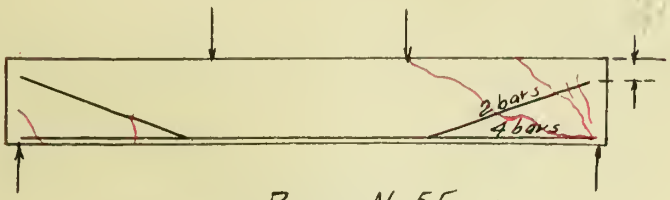
Beam No. 41



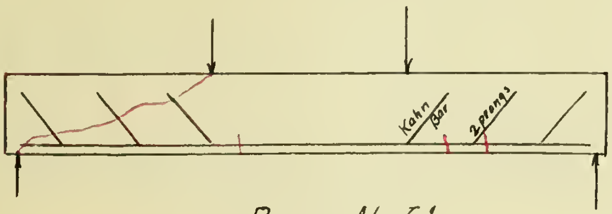
Beam No. 48



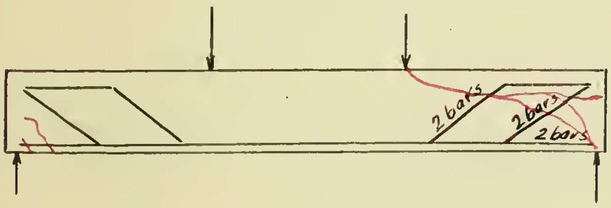
Beam No 51



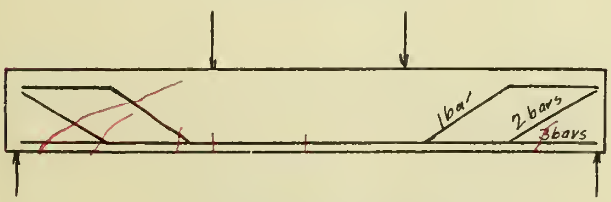
Beam No. 55



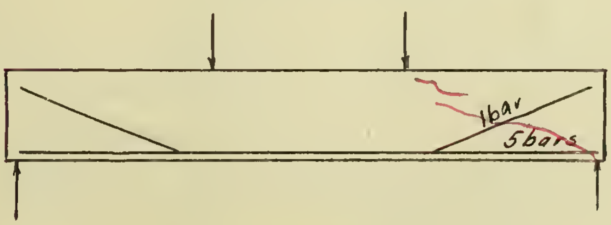
Beam No. 61



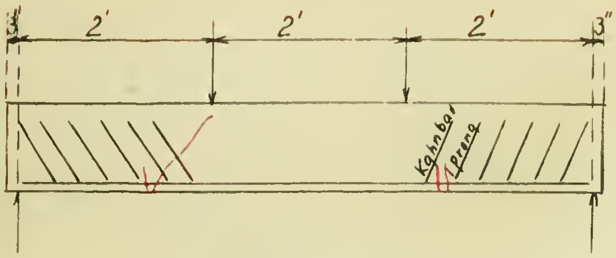
Beam No. 71



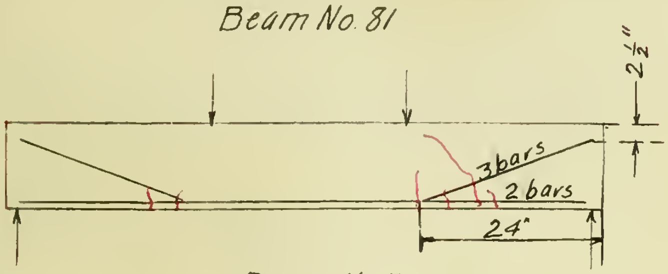
Beam No. 58



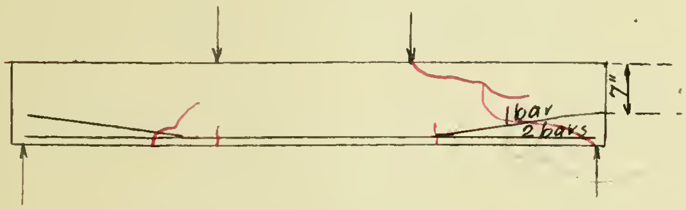
Beam No. 80



Beam No. 81

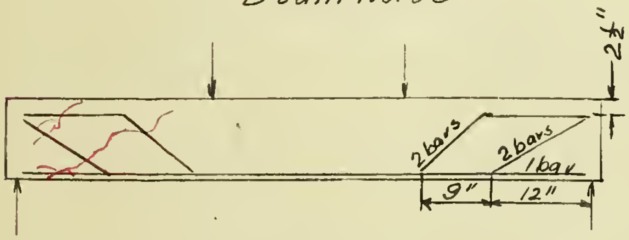


Beam No. 82

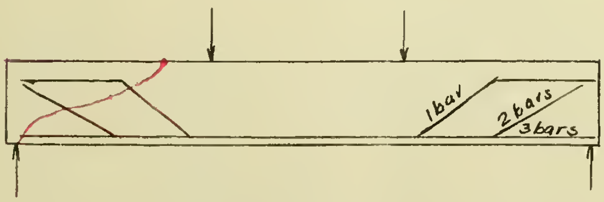


?

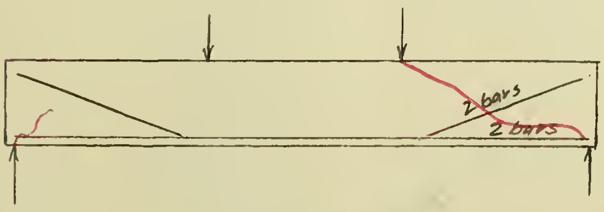
Beam No. 83



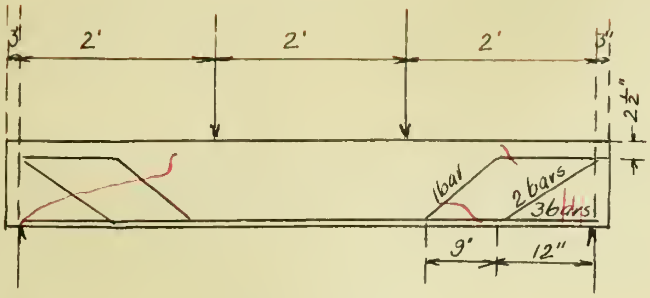
Beam No. 87



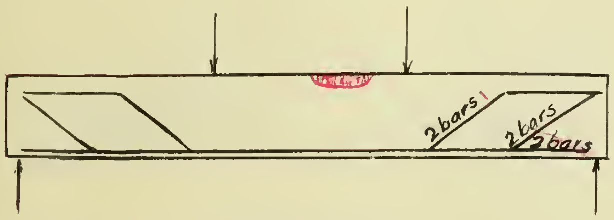
Beam No. 88



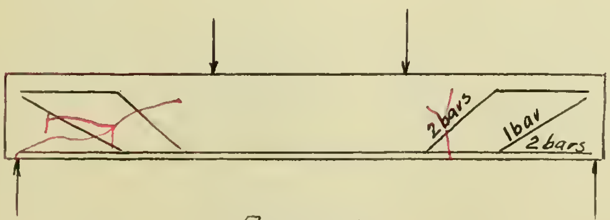
Beam No. 95



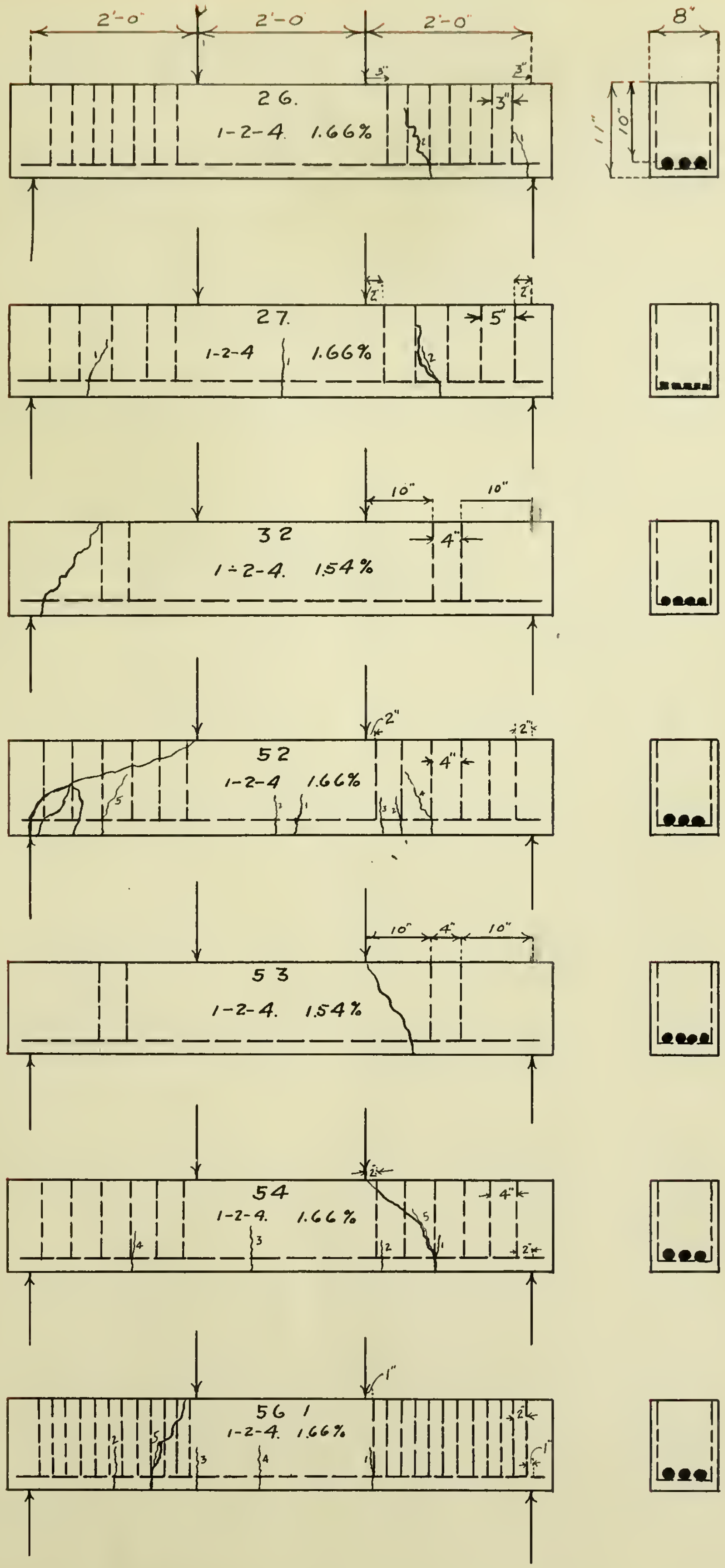
Beam 96

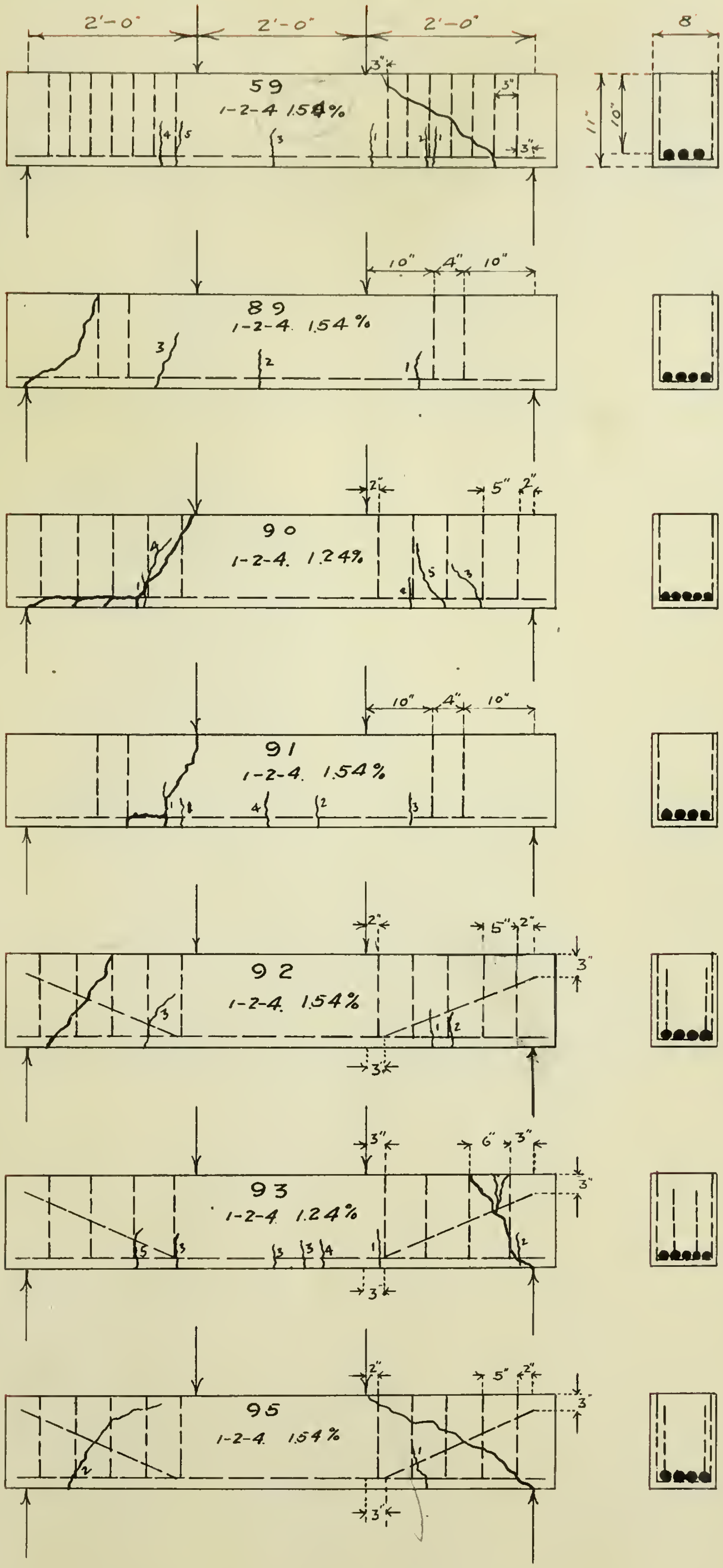


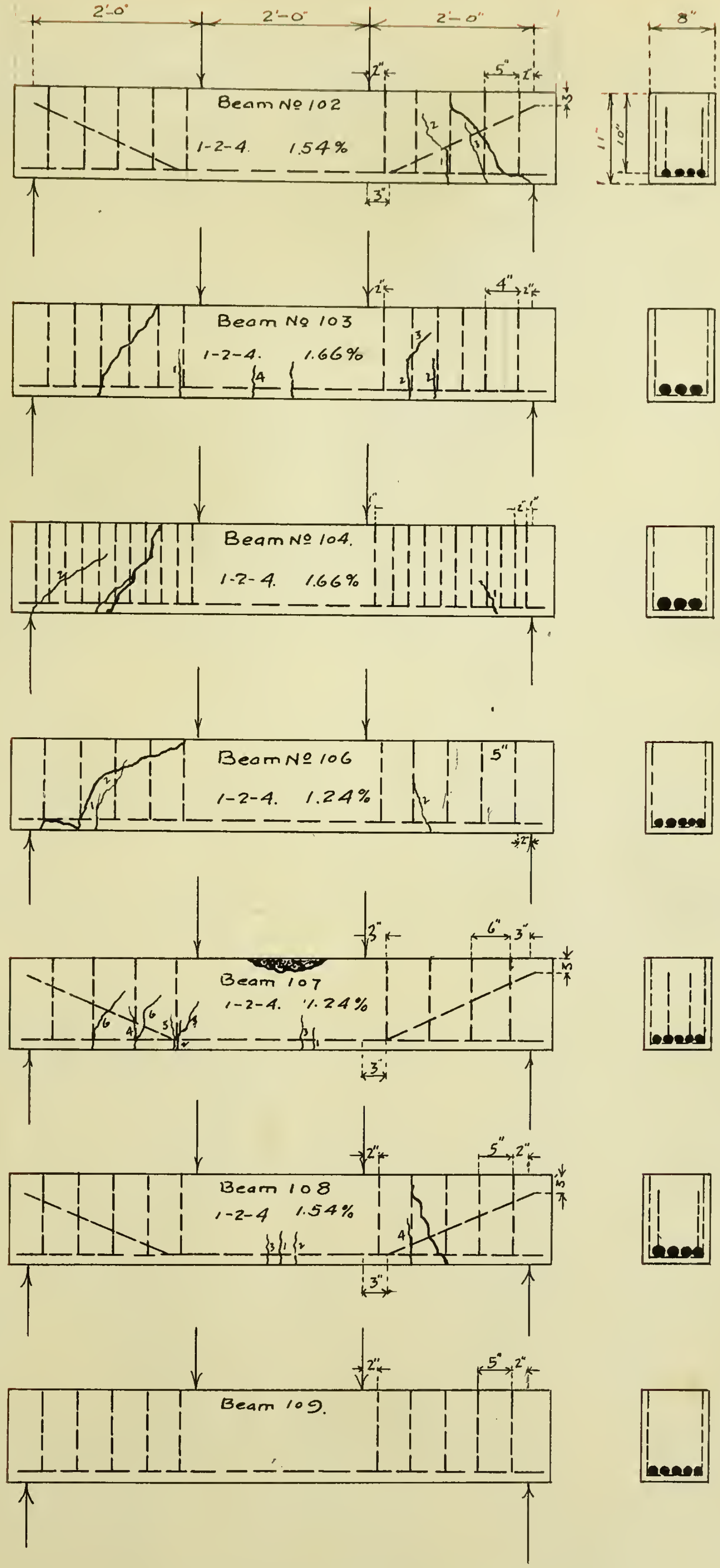
Beam 97

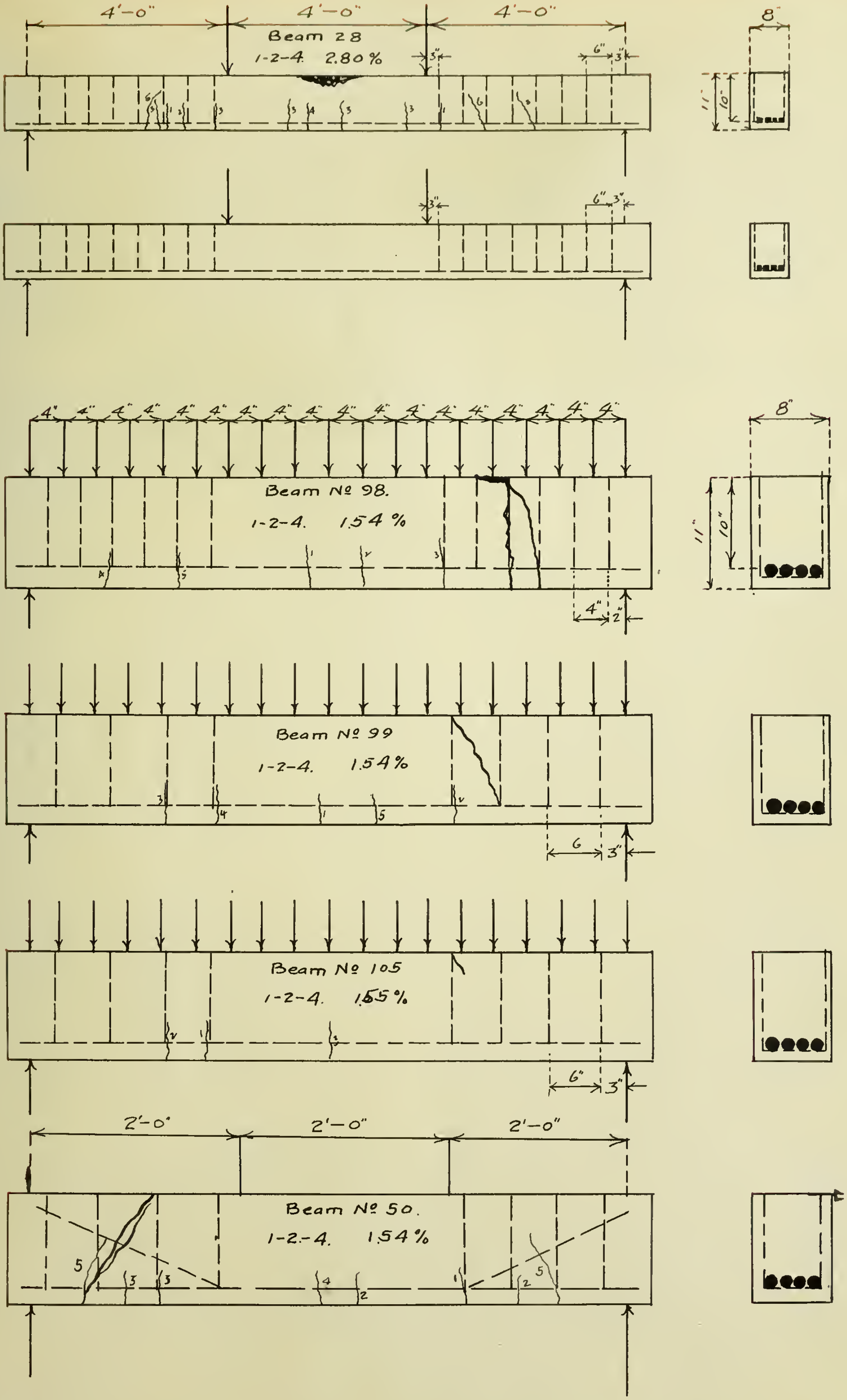


Beam 101


2'-0"
2'-0"
2'-0"
8"
11"
10"
26.
1-2-4. 1.66%
27.
1-2-4 1.66%
32
1-2-4. 1.54%
52
1-2-4 1.66%
53
1-2-4. 1.54%
54
1-2-4. 1.66%
56 1
1-2-4. 1.66%


2'-0"
2'-0"
2'-0"
8"
11"
10"
59
1-2-4 1.54%
89
1-2-4. 1.54%
10"
4"
10"
90
1-2-4. 1.24%
91
1-2-4. 1.54%
92
1-2-4. 1.54%
93
1-2-4 1.24%
95
1-2-4. 1.54%


2'-0"
2'-0"
2'-0"
8"
Beam No 102
1-2-4. 1.54%
11"
10"
Beam No 103
1-2-4. 1.66%
Beam No 104.
1-2-4. 1.66%
Beam No 106
1-2-4. 1.24%
Beam 107
1-2-4. 1.24%
Beam 108
1-2-4 1.54%
Beam 109.


4'-0"
4'-0"
4'-0"
Beam 28
1-2-4. 2.80%
8"
11"
10"
Beam № 98.
1-2-4. 1.54%
Beam № 99
1-2-4. 1.54%
Beam № 105
1-2-4. 1.55%
2'-0"
2'-0"
2'-0"
Beam № 50.
1-2-4. 1.54%

CURVES.

On the last pages of the thesis are curves showing the variation of the deflection of the beams as the Load is applied. For beams on which the extensometers were used a curve of the deformation of the upper fiber and the steel is also plotted.

The values given on the curves were reduced graphically from the readings of the extensometers.

Discussion.

A discussion of each part of the thesis will now be given under their respective Classes.

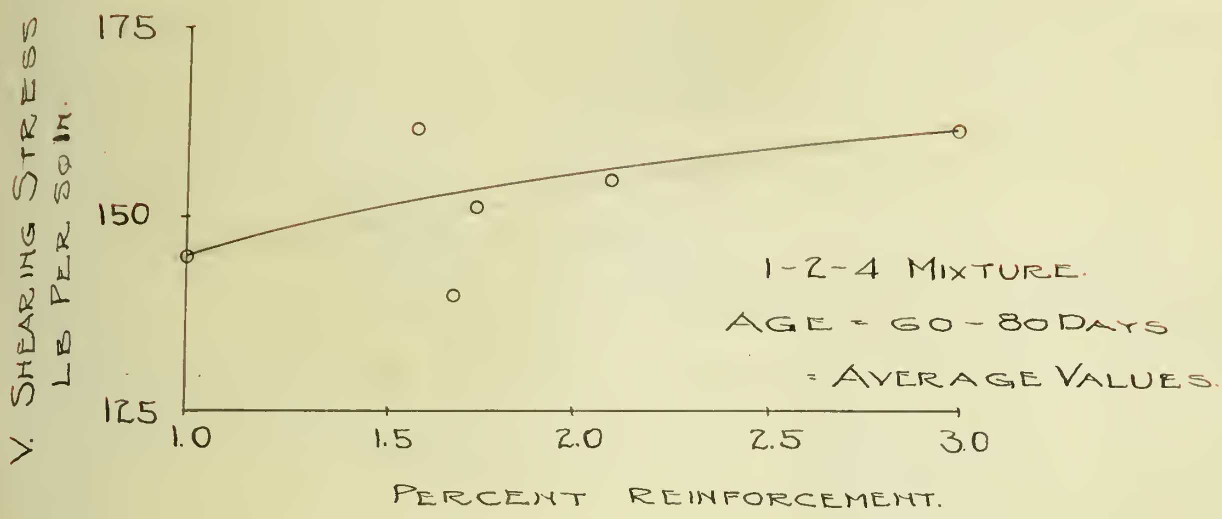
Class. A.

In this discussion the computed results given in Table 9 the positon of the cracks as shown by the sketches, and the behavior of the beam under load as shown in the load deflection diagrams, will be kept in mind.

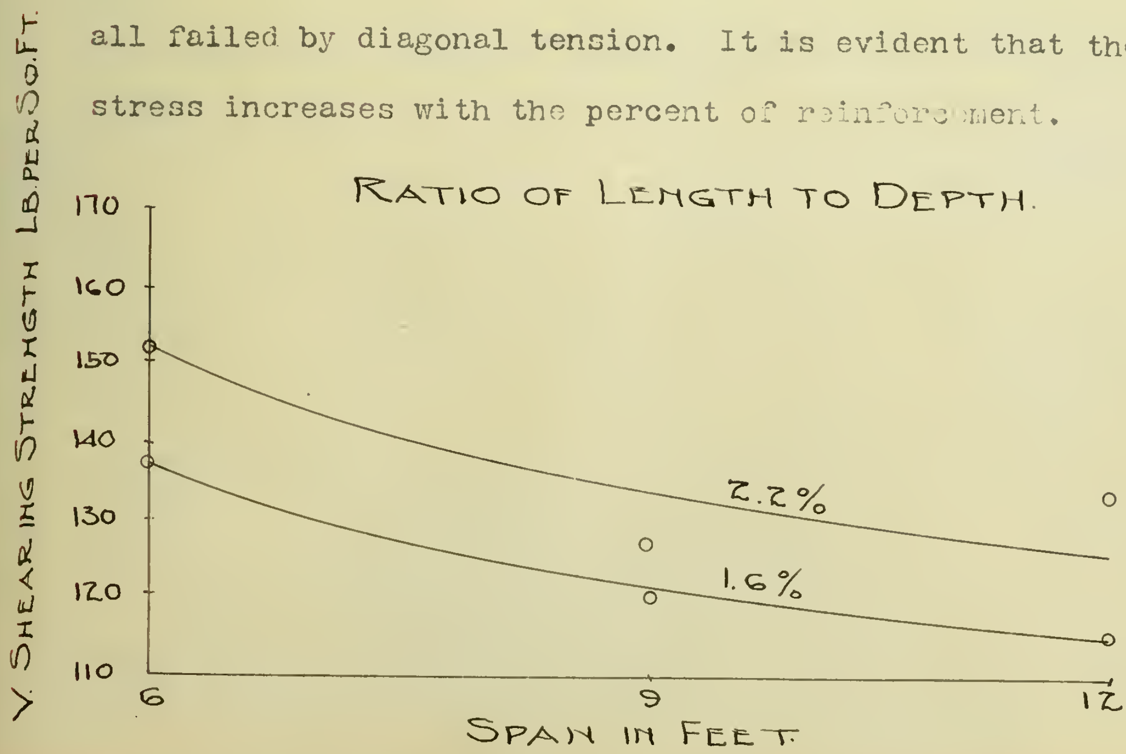
The vertical shearing unit stress will be used as the measure or means of comparison of the resistance of these beams to diagonal tensile stresses.

The test beam will be investigated for information along the lines of (a), effect of amount of reinforcing and (b) effect of length. These topics will be discussed in order, together with the relation of the strength of the beam to that of the auxiliary test pieces and the load at which the first diagonal cracks were noted. Generally speaking, the beams were planned to give diagonal tension failure and in the test under consideration only one beam was found to have failed by tension.

Effect of amount of reinforcement.



The above curve gives values of the vertical shearing stress developed with the several percentages of reinforcement used. These beams were all of 6 feet span, and 1-2-4 concrete and were tested at between 60 and 80 days of age, and all failed by diagonal tension. It is evident that the shearing stress increases with the percent of reinforcement.



In above figure have been plotted values of web resistance for two percentages of reinforcement and for three spans, that are thought to be representative of the results of these tests. The effect of the slenderness of the beams as well as the amount of reinforcement is shown in this diagram.

Appearance of Diagonal Cracks.

The applied load at which the first diagonal crack appeared was noted as often as possible as shown by the tables. In nearly all cases it appeared very shortly before, or just at the time of failure.

Relation of vertical shearing stress to modulus of rupture of auxiliary test beams, and Compressive strength of 6 inch cubes.

The modulus of rupture, determined from the tests of the control beams, is representative of the tensile strength of the concrete and may be used as a criterion of its strength, although it does not give the actual tensile strength of the concrete.

Table 15 gives the ratios of the vertical shearing unit stress of the reinforced concrete beams to the modulus of rupture of the control beams for the test beams for which control beams were made, the age of the beams being taken as about the same as that of the corresponding reinforced beam.

The ratio of the vertical shearing unit stress to the compressive strength given by the cubes is also shown in the same table, for the cases when all the conditions of tests compare.

Class B.

The beams reinforced with the Kahn bars varied about 20% in the nominal vertical shearing stress developed. They all had the same per cent, 1.78, of reinforcement.

In the series of beams reinforced by 6 - 1/2 in. round bars, there was a variation of 138 per cent. Beam No. 13 with 4 bars bent up failed at 35300 lb., and developed a nominal vertical shearing stress of 271 lb. per sq. in. Beam No. 88 with 3 bars bent up failed at 14300 lbs. and developed a nominal vertical shearing stress of 114 lb. per sq. in. The remainder of the beams of the series broke at about 23000 lbs. The small load carried by Beam No. 88 was due, perhaps, to poor concrete. Reference to the compressive strength of the cubes, corresponding to this beam shows the concrete in Beam 88 was exceptionally poor. The control beam shows that the tensile strength was poor also, the modulus of rupture developed by it, being only 127 lb. per sq. in. Beam No. 13 on the other hand was no doubt aided by a good quality of concrete. The compressive strength of the cube, corresponding to this beam was 2775 lb. per sq. in. which was considerably above the average. The control beam shows that the tensile strength of the concrete in Beam No. 13 was exceptionally good.

The results from Beams Nos. 82 and 87 are also noticeable. These beams were reinforced by 5 - 5/8 in. round bars. Beam No. 82 had 2 bars bent up and Beam No. 87 had 3 bars bent up.

The former broke at a load of 30000 lbs. and the latter at 19700 lb. The nominal vertical shearing stress developed was 232 and 153 lb. per sq. in. respectively. By referring to the tests of the cubes and control beam, the poor quality of the concrete in Beam No. 87 is at once evident.

Class C.

(a) Tensile Stress in Stirrups.

Beams No. 56, 104, 26, 59, 54, and 103 are considered under this head. All these beams are 6 ft. span and generally 1.66% reinforcement of plain round rods. They had stirrups of 1/4 in. square corrugated bars of 2, 3, and 4 in. in spacing. The tensile stress in the stirrups was computed from the formulae $P = \frac{V a}{d'}$ as explained above. The following table shows the results of the tests.

Beam NO.	Spacing of Stirrups.	Vertical Shearing Strength lb.per sq.in.	average Vert. Shearing Str.lb.per sq.in.
56	2	192	211
104	2	230	
26	3	144	145
59	3	146	
103	4	193	192
54	4	190	

All these beams, without exception, failed by diagonal tension. The use of stirrups does not seem to have any influence on the time of the appearance of the first diagonal crack. However, instead of failing suddenly as did the beams of Class A, these failures were gradual except in the case of Beam No. 26. The

stirrups, having begun to take the vertical component of the stress, when the cracks first appeared, prolonged the life of the beams considerably.

(b) Effect of Position of the Stirrups.

Beams No. 32, 89, 53, and 91 are discussed under this heading. All these beams were 6 ft. span and generally 1.54% plain round reinforcement. The stirrups were 1/2 in. square corrugated bars and 1/2 in. plain round bars. The following table shows some of the computed stresses.

All stirrups spaced 4 in.

Beam No.	Kind of stirrups.	No. of stirrups.	Shearing Stress lb. per sq.in.	Average Shearing Stress lb.per sq.in
32	sq.cor.bars.	2	122	
89	" "	2	141	132
53	Round plain rods.	2	172	
91	" "	2	122	147

All these beams failed by diagonal tension, the tensile stress in the stirrups being very low. The position of stirrups had no effect upon the time of appearance of the first crack. But after the beams were cracked, the position of the stirrups affected the manner of failure and the ultimate load carried. Reference to the sketches following the notes on tests will show that the final failure came at points outside the region reinforced with stirrups.

(c) Effect of Wire Mesh Reinforcement.

Beam No. 52 was reinforced with 1.66% plain round rods. The web reinforcement consisted of wire mesh spaced 4 in. A vertical shearing stress of 225 lb. per sq. in. was attained which is higher than what a similar beam without web reinforcement would carry. The first diagonal crack was noted at 24000 lb. giving a vertical shearing unit strength of 200 lb. per sq.in. While results of this one test may prove nothing yet it points to the conclusion that the wire mesh stirrups do not carry much stress. The high maximum load carried was probably due to the good quality of concrete and also to the great bond between the concrete and longitudinal steel. The beam failed rather suddenly by diagonal tension which showed that this form of web reinforcement was not as satisfactory as the ordinary form.

(d) Effect of Uniform Loading.

Beams 98, 99 and 105 were tested with uniform load. All of these had 1.54% of plain round longitudinal reinforcement. The stress in longitudinal reinforcement and tensile stress in stirrups, etc., are shown in Table 14. Considerable interest has been manifested in the comparative effect of method of loading test beams. The prevailing opinion is no doubt, that a uniformly distributed load will allow a higher moment of resistance to be developed. The accompanying shear and moment diagram Fig. 2 show the distribution of these values due to uniform loading.

Each stirrup in the beam has different tensile and bond stresses due to the different shearing stress throughout the length of the beam(See shear and moment diagrams.) The maximum load in Beams 98 and 99 was 30000 lb. In the former failure was sudden. One stirrup broke after slipping through the concrete at the top. The latter failed by diagonal tension. The Characteristic features of uniform loading are that the tensile cracks are more distributed and also the deflection of the beam at the center is comparatively small.

(e) Effect of Corrugated Bar Longitudinal Reinforcement.

Beams 27, 106, 90, 109, 28, and 110 are considered under this heading. All beams failed by diagonal tension except Beam 28 which failed by the compression of concrete. The high steel corrugated bars had an elastic limit of 60000 lbs. per sq.in. and its bond stress is exceedingly high. But according to Table 14 the maximum applied load and bond stresses of longitudinal reinforcement are exceedingly low, especially as shown by Beam 28 which has 2.08% longitudinal reinforcement. Therefore it is very hard to discuss the effect of corrugated bar longitudinal reinforcement from these tests. This is true also because of the poor results due to the bad quality of concrete as shown by the control Beam No. 90 and 106, Table 14.

(f) Effect of Bending up Part of Longitudinal Bars.

Beams 50, 92, 93, 102, 107, 108. are considered under this subject. Longitudinal reinforcement varied from 1.24%

to 1.54% . According to the examination of Table 14 the results are very satisfactory. Except Beams 92 and 93 which are due to the poor concrete as shown by the control beams. Beams 92, 102, and 108 failed by diagonal tension, Beam 50 by diagonal tension and slipping of stirrup, Beam 93 by slipping of stirrup, and Beam 107 by compression of concrete at center.

The inclined crack usually appeared first, due to the rupture of the concrete in tension. To assist in preventing this rupture in its initial state the most efficient reinforcement would be such as supplied by the bent up bars. Reinforcement in this direction is in a position to take stress immediately. The stirrups can hardly be as effective as bent up bars, in preventing initial rupture, for so long as the concrete is intact the deformation on a vertical line is practically zero, owing to the combined action of web tension and web compression at right angles to each other. Unless the unit stress in the steel be made very low, howevrr, it is likely that the concrete has received excessive tensile stress even under working conditions. It may be assumed to be ruptured more or less in the same manner as on the tension face of the beam at points of maximum moment. At least the distortion in tension will be greater than in compression, and there will be a vertical movement of the concrete on the side of the crack and the stirrups will be brought to direct action. Stirrups are more effective than bent up bars after a diagonal crack is formed. Therefore beams having the bent up bars and also stirrups have effective web reinforcement.

V.

CONCLUSION.

---------0----------

The conclusions drawn from each class of tests will first be stated and then a general conclusion for the entire series of tests will be drawn. The conclusions from the tests in each class are as follows:-

Class A.

The results of the experiments under Class A agreed very closely with those of the Bulletin No. 29. The beams may be said to have failed by diagonal tension, and with very few exceptions, very suddenly. The bond stress in pounds per square inch agrees very closely with that of the Bulletin.

From the sketches of the Beams, pages 46 and 47 when the very sudden failure occurred the crack ran direct from load point to support as in Beams 7 , 17 and 22.

The 9 and 12 ft. beams acted to a great extent like the 6 ft. beams when failing.

The curve showing Effect of Amountof Reinforcement on resistance to diagonal tension, page 59 shows a gradual increase of strength with the increase of the amount of reinforcement.

The curve of Effect of Ratio of Length of Span to Depth of Beam page 59 is not all that is desired, as the tests were not very complete and not enough points were obtained but by taking average values, curves were obtained that are

fairly representative.

These curves show a decrease in strength, as the beams increase in length, which is very uniform. The curves for different amounts of reinforcement are parallel.

The curves at the back of this thesis are typical of the beams tested and agree very well with former experiments.

It may be said that beams without web reinforcement fail very suddenly by diagonal tension. Beams of 1 - 2 - 4 concrete, made as previously described, with 1.6% reinforcement fail at from 153 to 132 lb. per sq. in. vertical shearing stress and those of 2.2% reinforcement from 137 to 115 lb. per sq. in. for from 6 to 12 ft. spans. Beams 6 ft. in length and made as described above stand from 145 to 162 lb. per sq. in. when having from 1% to 3% reinforcement.

Class B.

All the beams in this class fail by diagonal tension except Beam No. 97 . It failed by compression in the concrete at the center.

By refering to the log of the beams and the diagrams on pages 48-52, the position and load at which the cracks formed may be found.

A vertical crack generally formed in the outer third of the beam at the bottom and extended to the reinforcement. The formation of these cracks was due to the failure of the concrete in tension. A diagonal crack usually formed from one or

two of these vertical cracks and spread towards the adjacent load point. Failure took place along one of the diagonal cracks.

By comparing the nominal vertical shearing stress developed by the beam as well as the corresponding control beams and cubes, the following results are secured.

(a) The effect of the different types of Kahn bars.

The bar marked B proved to be the best. This bar had the prongs staggered and bent to an angle of 50° with the horizontal.

(b) The effect of the number of bars bent up.

(1) Plain round bars. To bend up 4 bars when 6-1/2 in. bars are used gives better results than to bend up 3 bars. To bend 3 bars gives better result than to bend up 2 bars. To bend up 2 bars gives better results than to bend up 1 bar.

(2) When 5 1/2in round bars are used , 3 bars bent up from a point 24 in. from the end to a point 2 1/2 in. from the top and 3 in. from the end of the beam gives a nominal vertical shearing stress, 53% higher than when 4 bars are bent up two of which are from ~~the~~ a point 24 in. from the end to a point 15 in. from the end of the beam and 2 1/2 in. from the top of the beam and then parallel to the top to a point 3 in. from the end of the beam and two, of which are bent up ~~at~~ 15 in. from the end to a point 2 1/2 in. from top and 3 in. from the end of the beam.

(3) When 5 - 5/8 in. round bars are used, one bar bent up to point 2 1/2 in. from the top of the beam and 3 in. from

the end gives results 21% higher than when one bar is bent up to a point 7 in. from the top of the beam and 3 in. from the end of the beam . Three bars bent up, one of which is bent to a point 15 in. from the end of the beam and 2 1/2 in. from the top and then parallel to the top of the beam gives results a trifle higher than when two bars are bent up to a point 2 1/2 in. from the top of the beam and 3 in. from the end.

(4) Corrugated round bars. When 6 1/2 bars are used it does not seem to make any material difference whether 4 bars are bent up, 2 bars bent up to a point 15 in. from the end of the beam and 2 1/2 in. from the top and then parallel to the top of the beam and 2 bars to a point 2 1/2 in. from the top of the beam and 3 in. from the end, the break from the horizontal in these latter bars coming 15 in. from the end of the beams or whether 3 bars are used. Three or ~~4~~ Four bars ~~sound~~ bent up in the above way reinforce the beam 40% better than 2 bars bent up from a point 24 in. from the end of the beam to a point 2 1/2 in. from the top and 3 in. from the end of the beam.

(5) Corrugated square bars. The results with 6 1/2 square corrugated bars are extraordinary. Beam No. 58 reinforced with 6 1/2 square bars 3 of which ~~was~~ were bent up, was the stronger beam, although its percent of reinforcement was lower than 6 other beams. Two bars were bent up from a point 15 in. from the end of the beam to a point 2 1/2 in. from the top and 3 in. from the end of the beam. One bar was bent up to a point

15 in. from the end and 2 1/2 in. from the top then parallel to the top to a point 3 in. from the end of the beam. Beam No 71 had 4 bars bent up in a similar manner, yet the nominal vertical shearing stress developed was 33% smaller.

Class C.

In the beams with web reinforcement, web resistance depends upon the stirrups, the quality of concrete, and the strength of concrete.

The vertical stirrups spaced a distance apart equal to or greater than the depth of the beam will give little aid in the prevention of diagonal cracks between successive stirrups although they may prevent final failure by the extension of a crack horizontally along the reinforcing bars.

Beams provided with U shaped stirrups which passed under straight reinforcing bars generally gave high web resistance and slow failure was an important element. The stirrups do not come into action, at least not to a great extent, until the diagonal crack is formed.

The tests and calculations go to show that under maximum load applied to the beam the stirrups are not stressed to take entire vertical shear. In the beams with stirrups and part of the bars bent up the bond stresses of stirrups are a small fraction of the entire vertical shear. From examinations of table 14 it seems that there is considerable variation in results in the beams of the same making. This is due to the

web resistance of beams. Therefore , a high factor of safety is necessary to design the beams with web reinforcement for practical work.

GENERAL CONCLUSION.

--------0--------

The results and conclusions of this thesis may be sumarized as follows:-

(1) With but six exceptions, the failure in all classes of beams was by diagonal tension.

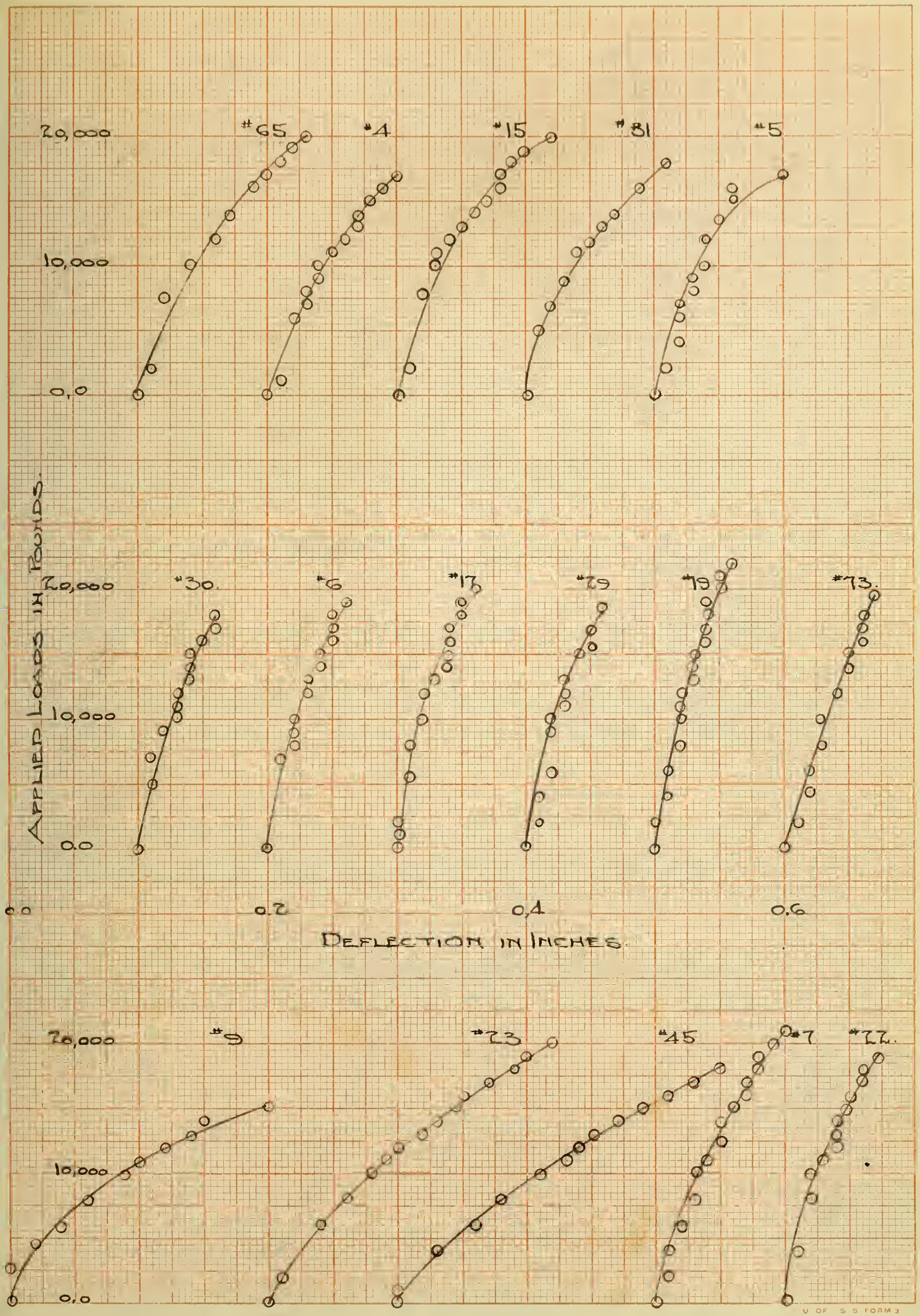
(2) Beams with their web reinforced by bent up rods gave a greater strength than beams without web reinforcement.

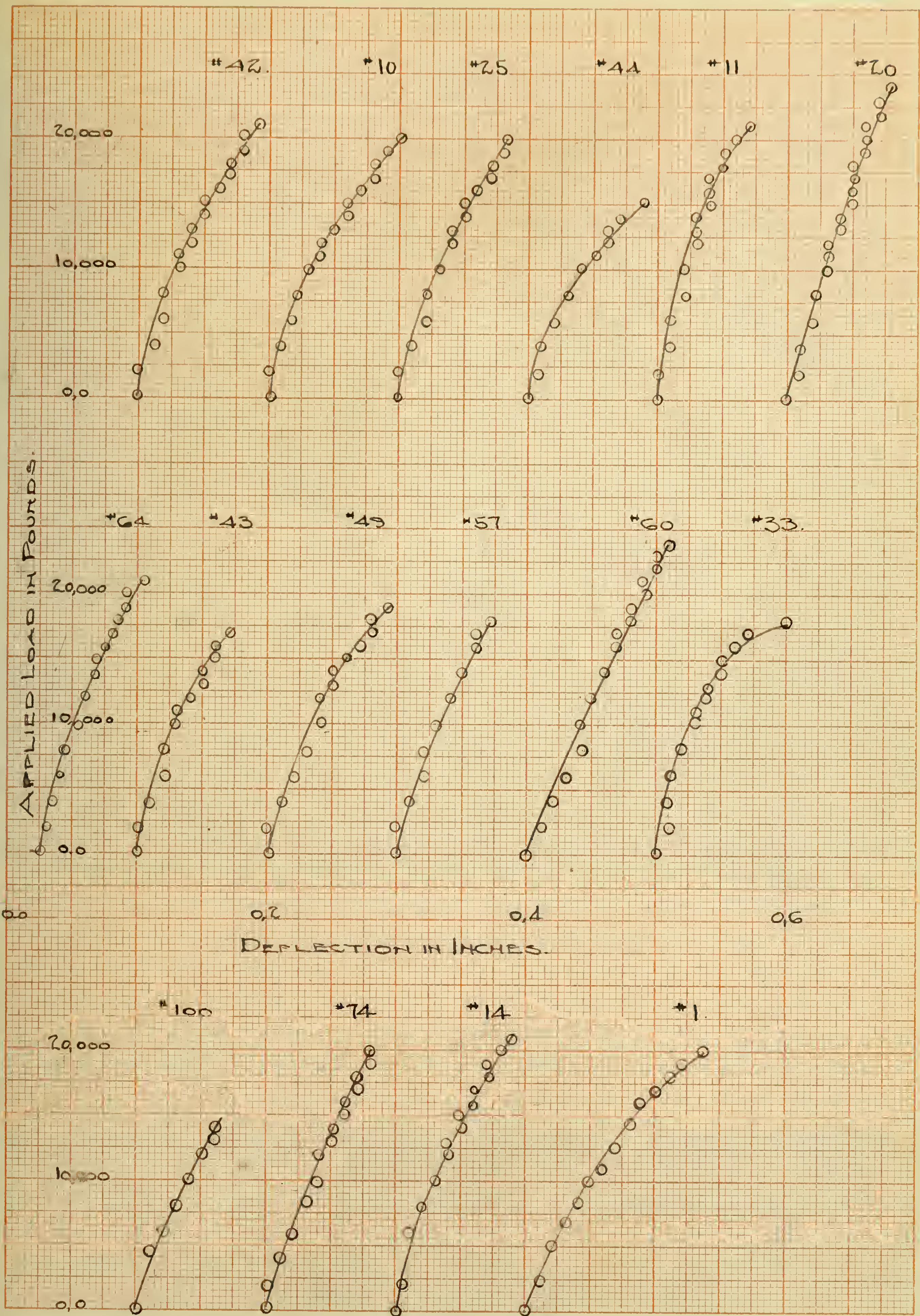
(3) Beams having their web reinforced with bent up bars had a greater strength than those having their web reinforced with stirrups alone.

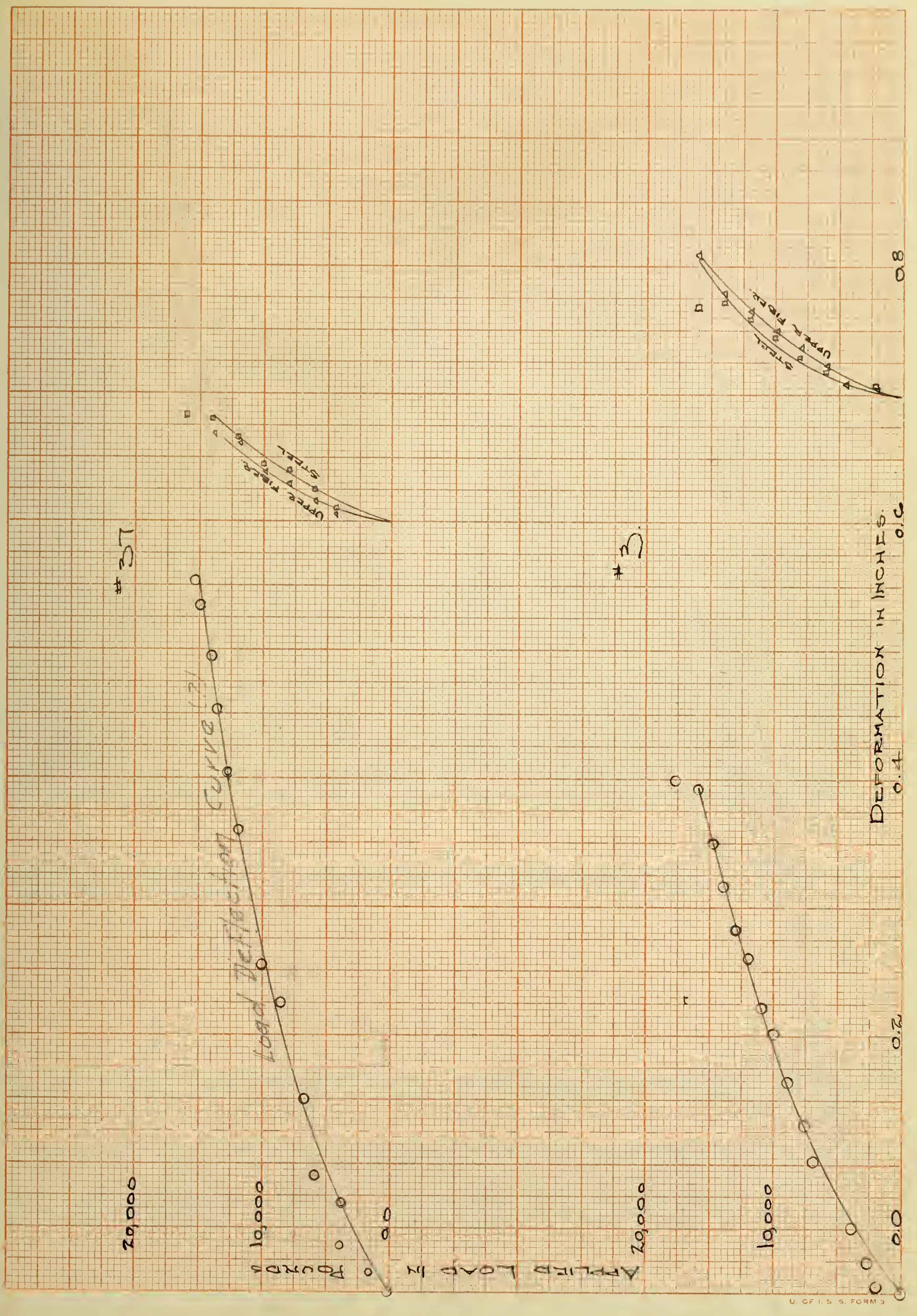
(4) Beams having their webs reinforced with bars bent up fail more suddenly than those whose webs are reinforced with stirrups.

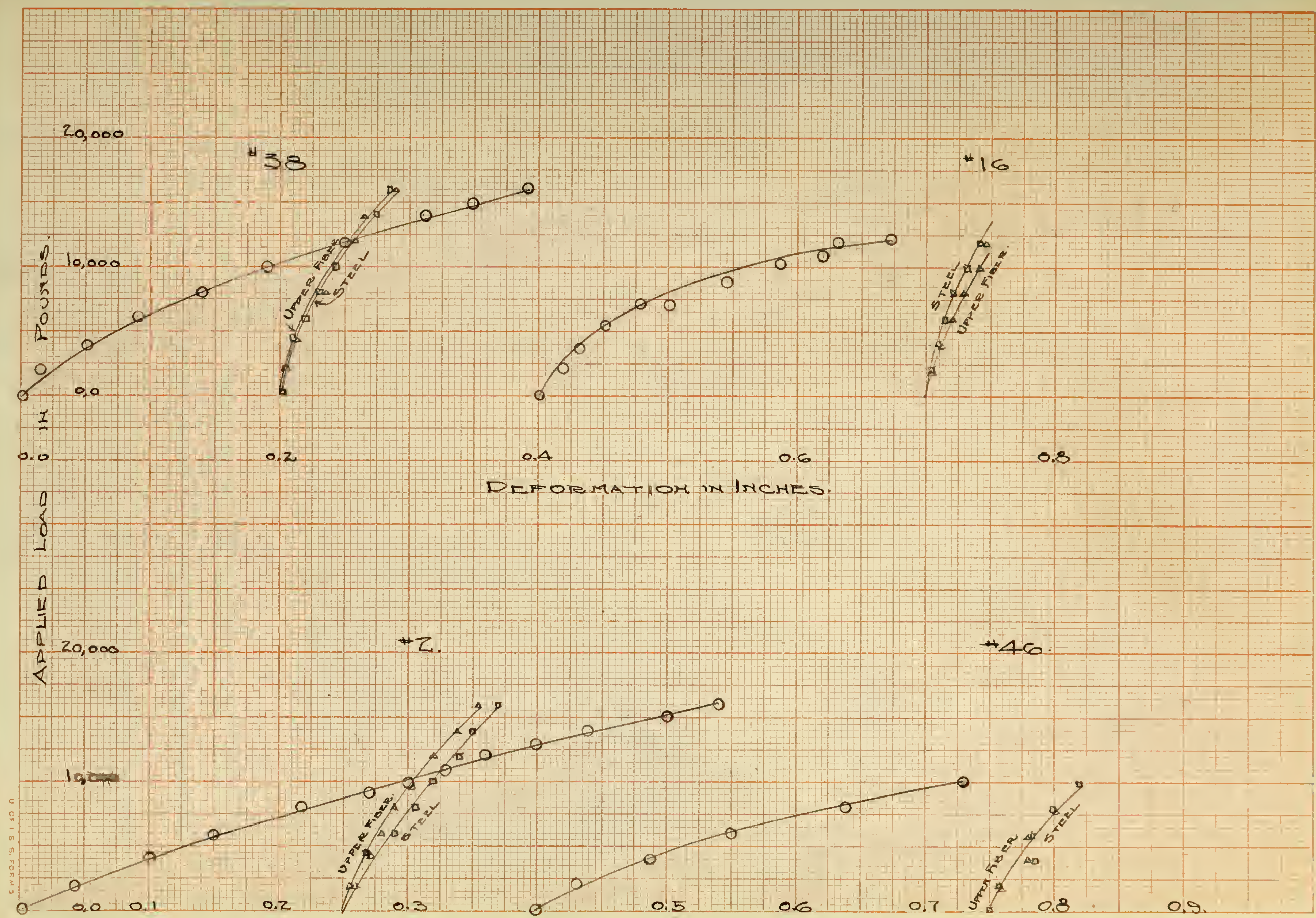
(5) Beams with webs reinforced with rods bent up and stirrups gave a greater strength than those with webs reinforced with rods bent up alone.

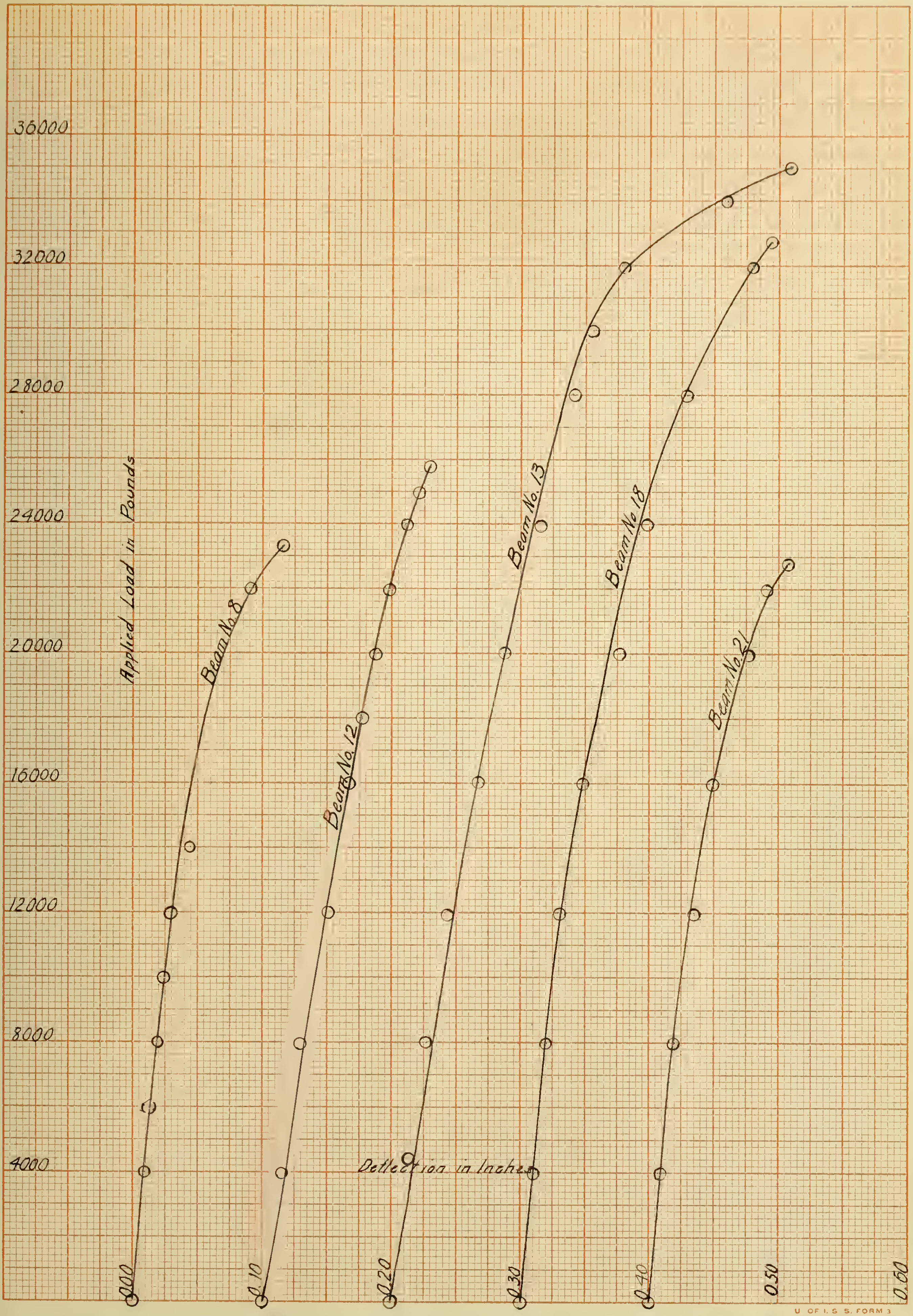
(6) Beams with webs reinforced, have a much greater strength than those without and fail much more gradually.

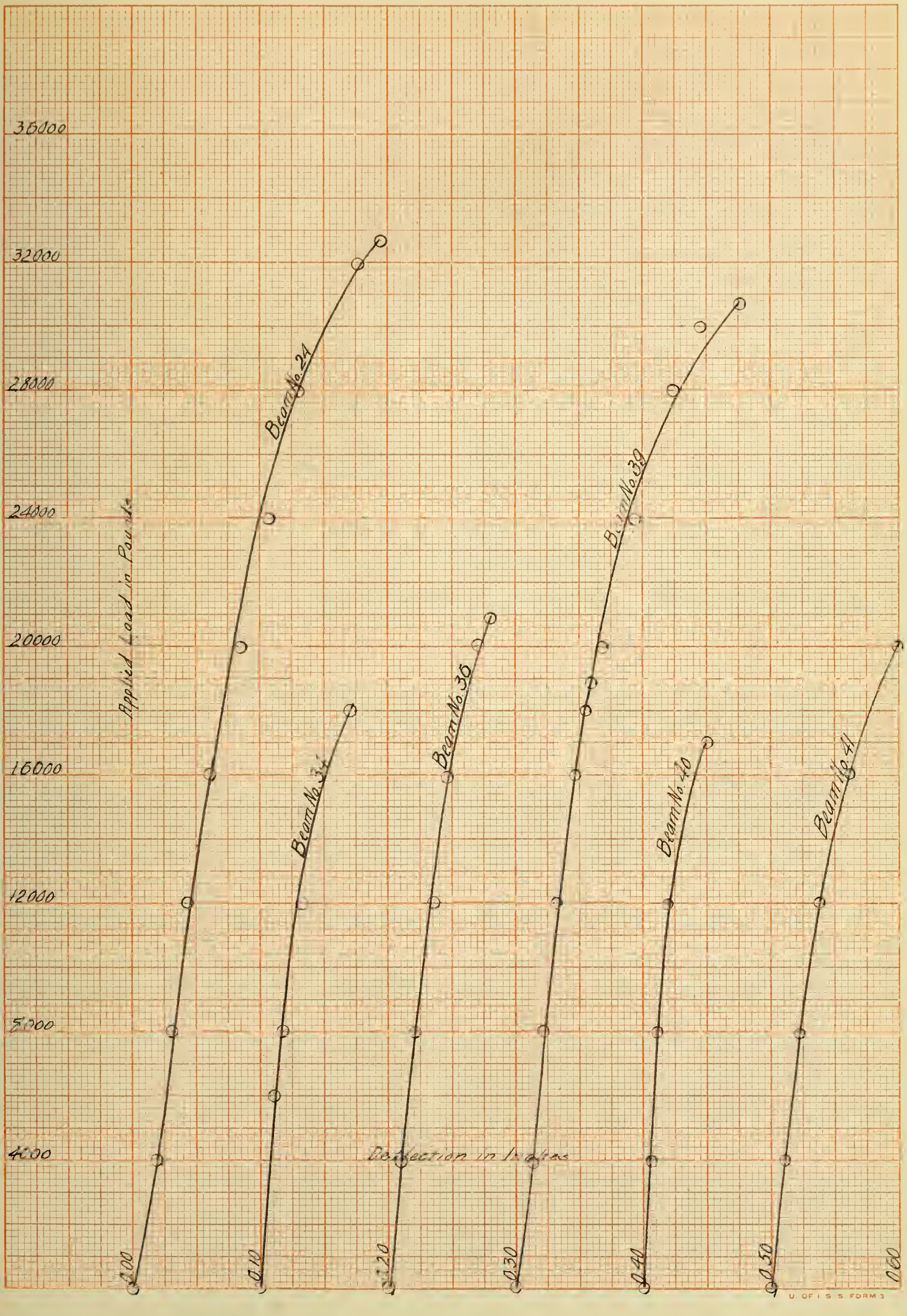

20,000
#65
#4
#15
#81
#5
10,000
0.0
Applied Loads in Pounds.
20,000
#30.
#6
#17
#29
#19
#73.
10,000
0.0
0.0
0.2
0.4
0.6
Deflection in Inches.
20,000
#9
#23
#45
#7
#22.
10,000
0.0

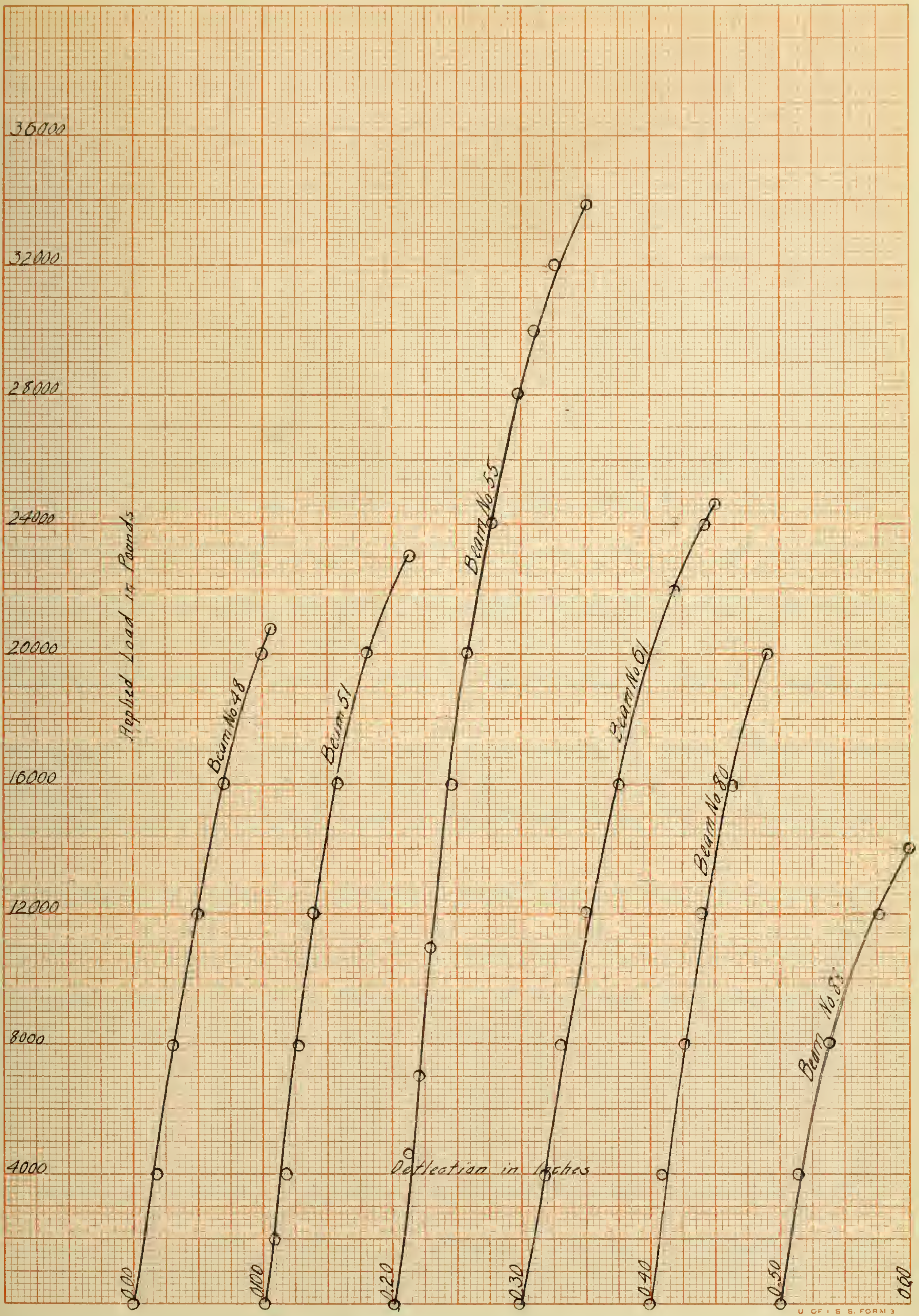

#42.
#10
#25
#44
#11
#20
20,000
10,000
0,0
APPLIED LOAD IN POUNDS.
#64
#43
#49
#57
#60
#33.
0,0
0,2
0,4
0,6
DEFLECTION IN INCHES.
#100
#74
#14
#1
U. OF I. S. S. FORM 3

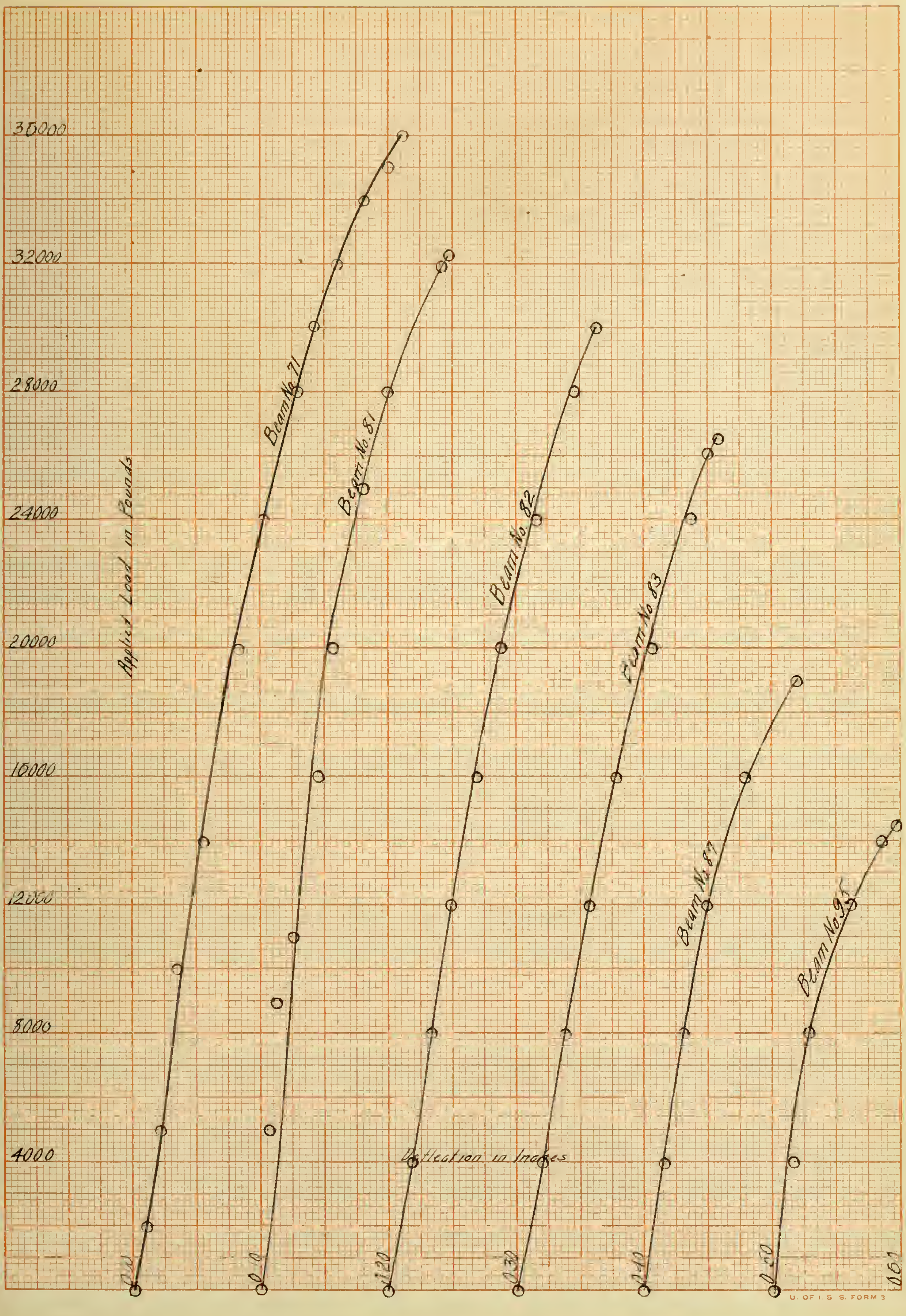

APPLIED LOAD IN POUNDS
DEFORMATION IN INCHES
0.0
0.2
0.4
0.6
0.8
10,000
20,000
#37
#3
Load Deflection Curve (?)
UPPER FIBER
STEEL
U. OF I. S. S. FORM 3

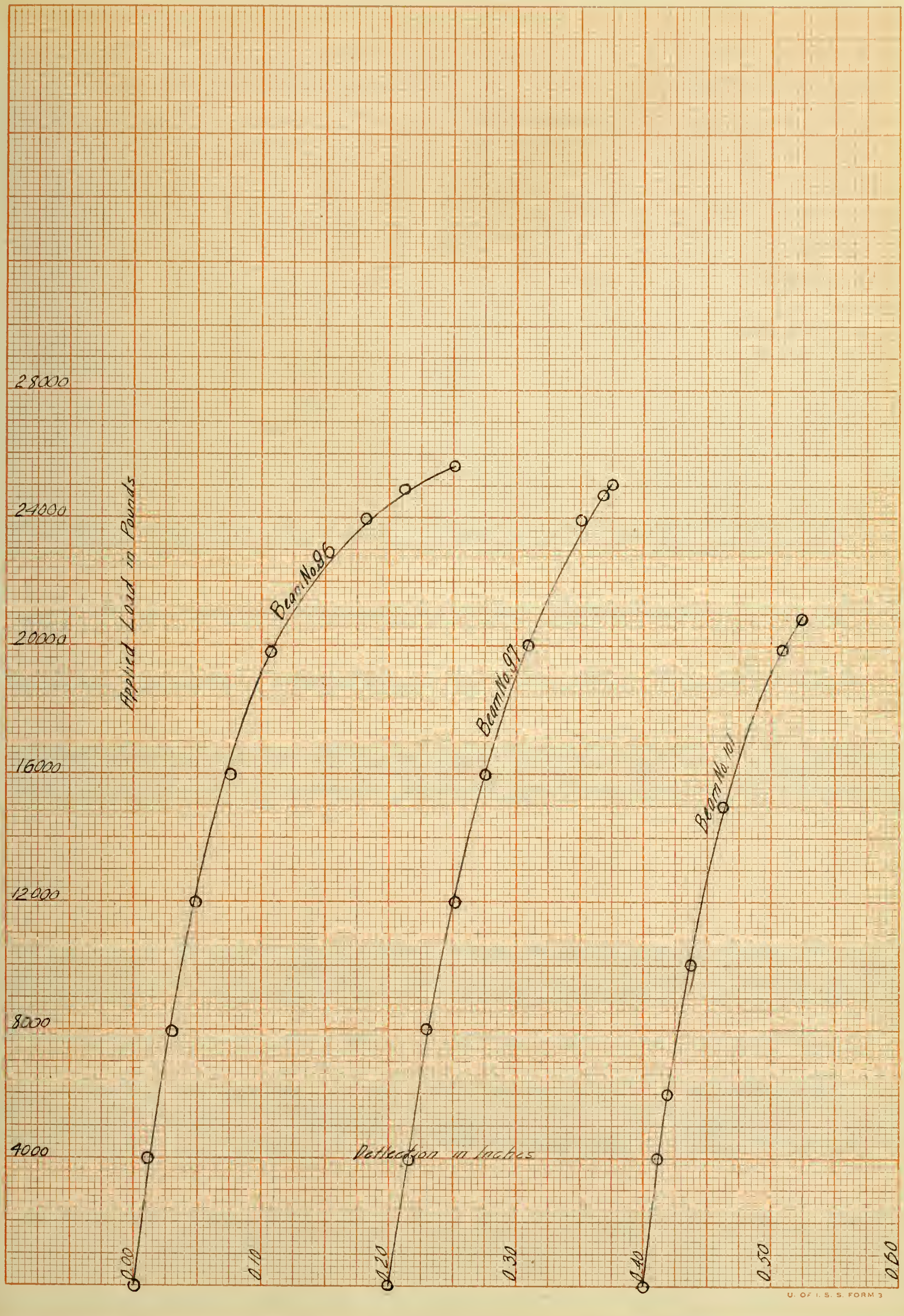

#38
#16
#2.
#46.
20,000
10,000
0.0
20,000
0.0
0.2
0.4
0.6
0.8
0.0
0.1
0.2
0.3
0.5
0.6
0.7
0.8
0.9
DEFORMATION IN INCHES.
APPLIED LOAD IN POUNDS.
UPPER FIBER
STEEL
U OF I S S FORM 3

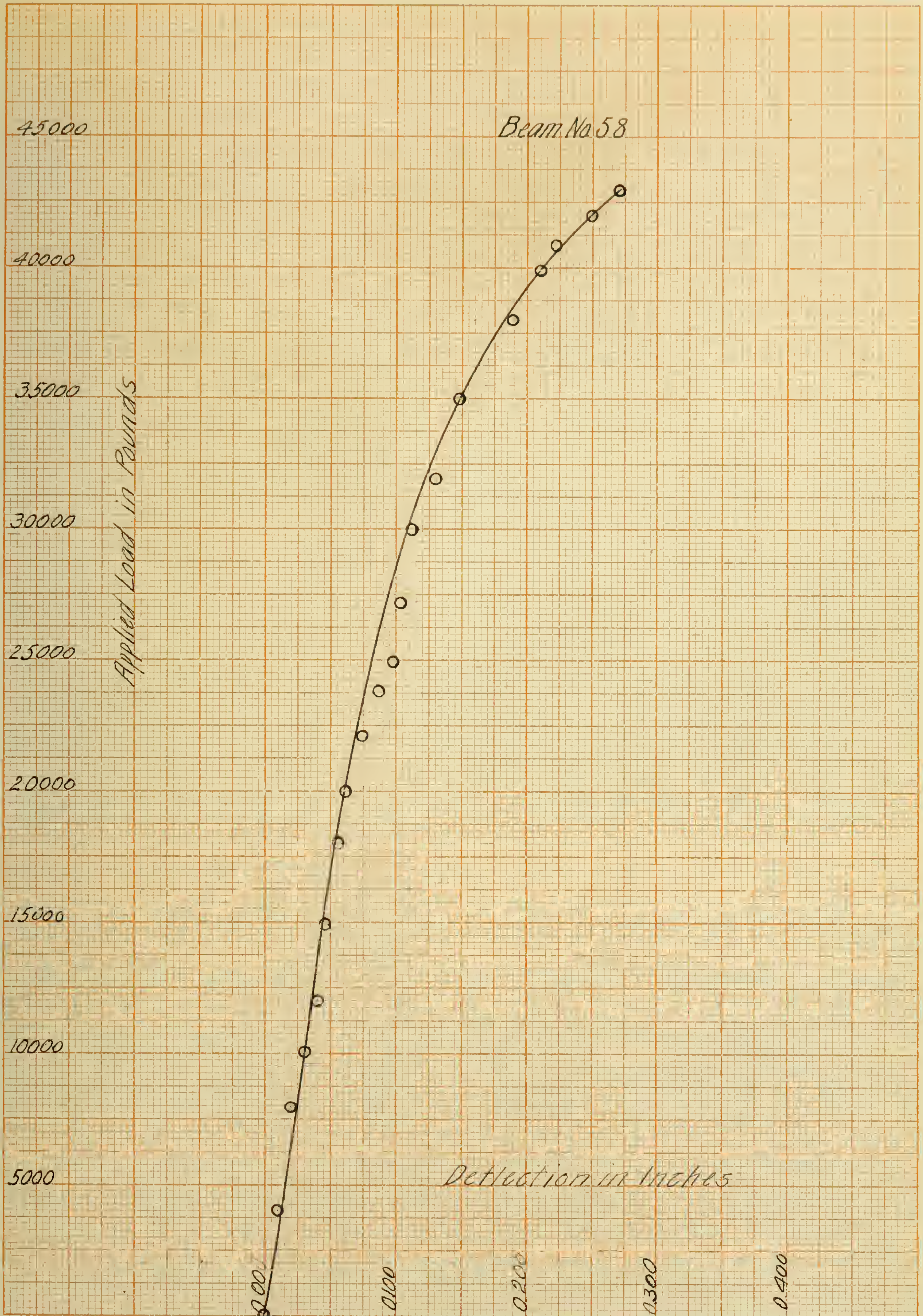

36000
32000
28000
24000
20000
16000
12000
8000
4000
Applied Load in Pounds
Beam No. 8
Beam No. 12
Beam No. 13
Beam No. 18
Beam No. 21
Deflection in Inches
0.00
0.10
0.20
0.30
0.40
0.50
0.60
U OF I. S. S. FORM 3


36000
32000
28000
24000
20000
16000
12000
8000
4000
Applied Load in Pounds
Deflection in Inches
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Beam No. 24
Beam No. 34
Beam No. 36
Beam No. 39
Beam No. 40
Beam No. 41
U. OF I. S. S. FORM 3

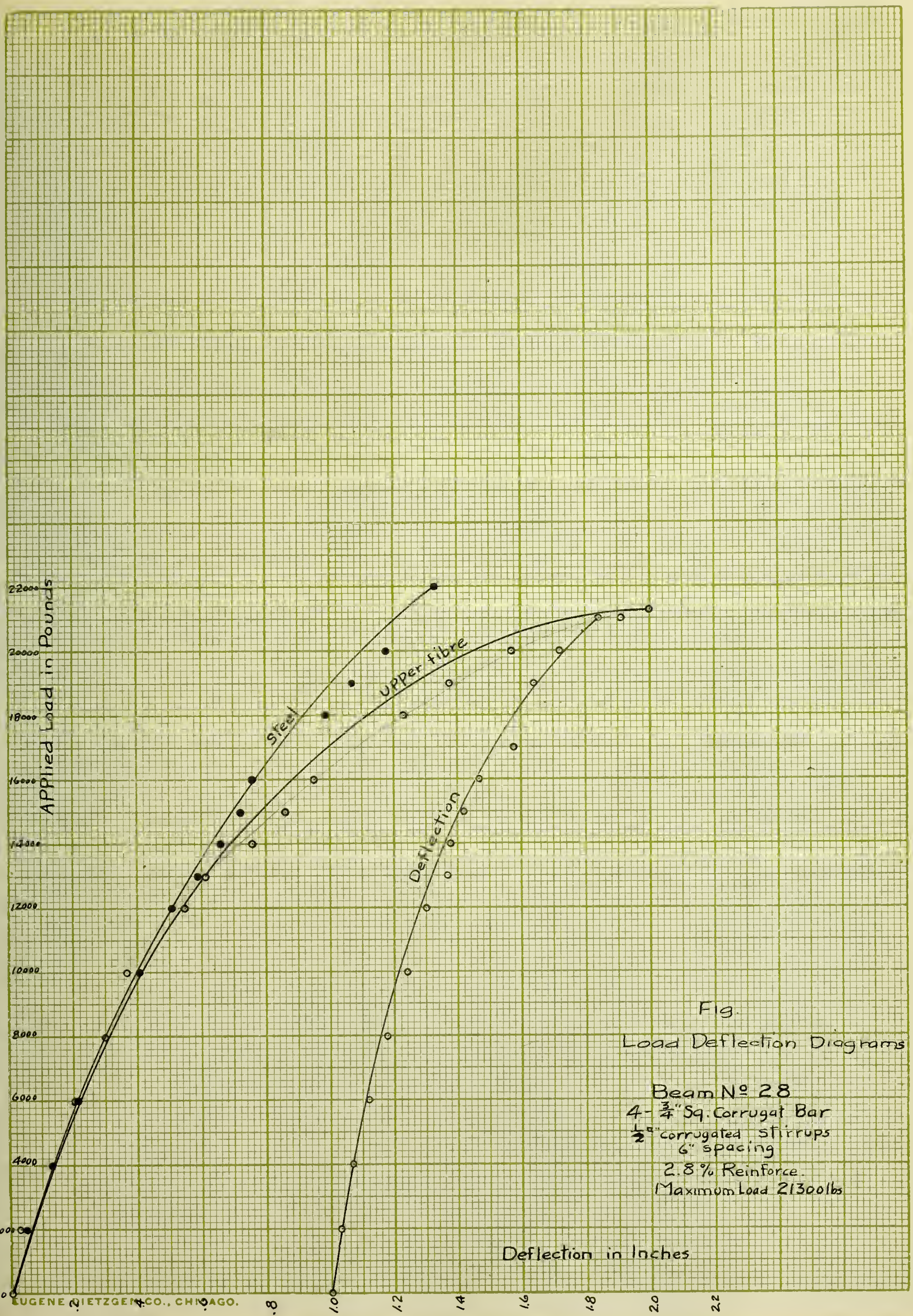

36000
32000
28000
24000
20000
16000
12000
8000
4000
Applied Load in Pounds
Deflection in Inches
0.00
0.10
0.20
0.30
0.40
0.50
0.60
Beam No 48
Beam 51
Beam No 55
Beam No 61
Beam No 80
Beam No 83
U OF I S S. FORM 3


35000
32000
28000
24000
20000
16000
12000
8000
4000
Applied Load in Pounds
Deflection in Inches
Beam No. 71
Beam No. 81
Beam No. 82
Beam No 83
Beam No. 87
Beam No. 95
0.00
0.10
0.20
0.30
0.40
0.50
0.60
U. OF I. S. S. FORM 3


28000
24000
20000
16000
12000
8000
4000
Applied Load in Pounds
Beam No. 96
Beam No. 97
Beam No. 101
Deflection in Inches
0.00
0.10
0.20
0.30
0.40
0.50
0.60
U. OF I. S. S. FORM 3



Beam No 58
Applied Load in Pounds
45000
40000
35000
30000
25000
20000
15000
10000
5000
Deflection in Inches
0.000
0.100
0.200
0.300
0.400


Applied Load in Pounds
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Steel
Upper fibre
Deflection
Fig.
Load Deflection Diagrams
Beam № 28
4- $\frac{3}{4}$" Sq. Corrugat. Bar
$\frac{1}{2}$" corrugated stirrups
6" spacing
2.8 % Reinforce.
Maximum Load 21300 lbs
Deflection in Inches
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
EUGENE DIETZGEN CO., CHICAGO.

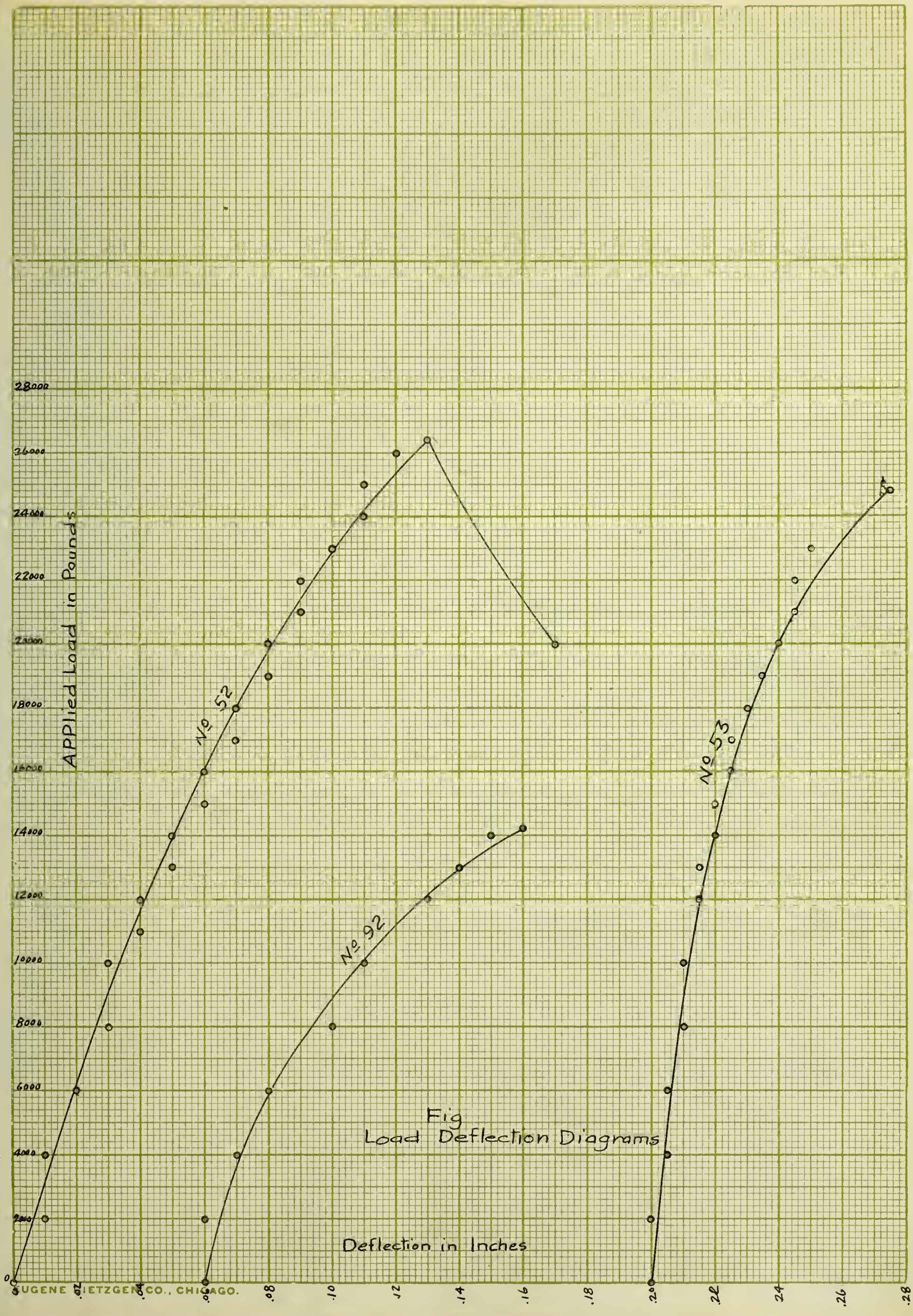
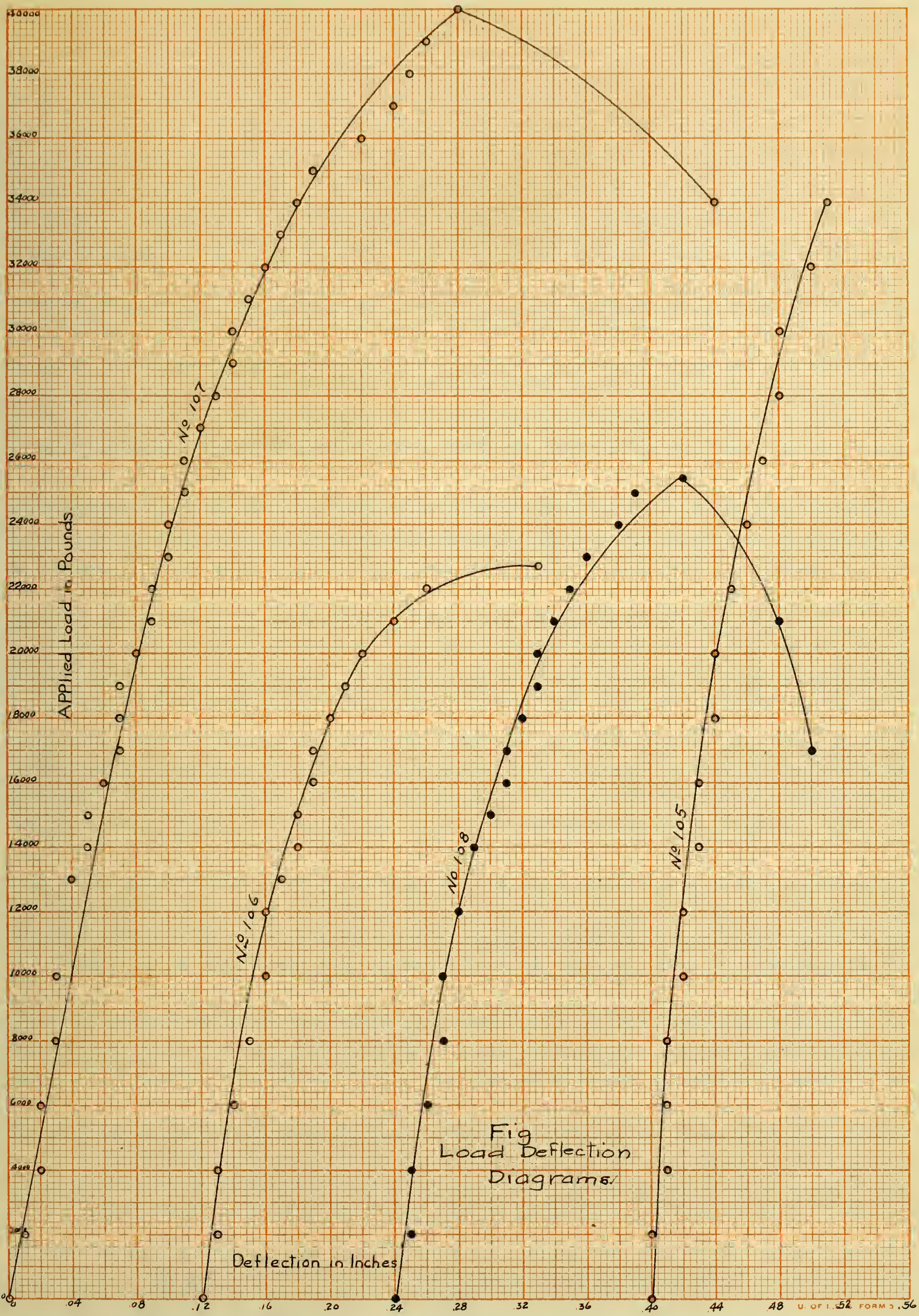


Fig
Load Deflection Diagrams



40000
38000
36000
34000
32000
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
0
.04
.08
.12
.16
.20
.24
.28
.32
.36
.40
.44
.48
.52
.56
APPlied Load in Pounds
Deflection in Inches
No 107
No 106
No 108
No 105
Fig
Load Deflection
Diagrams
U. OF I. FORM 3

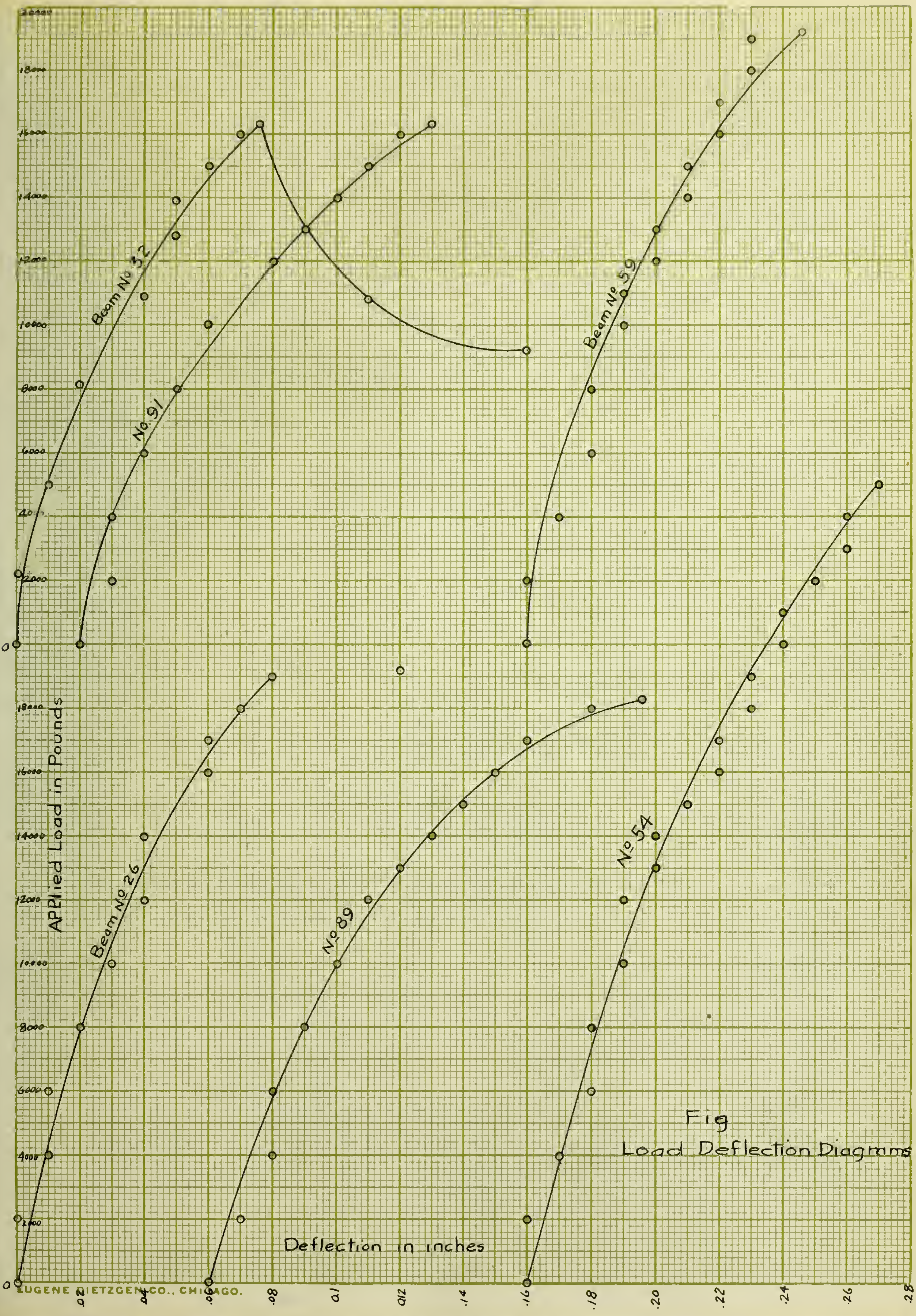
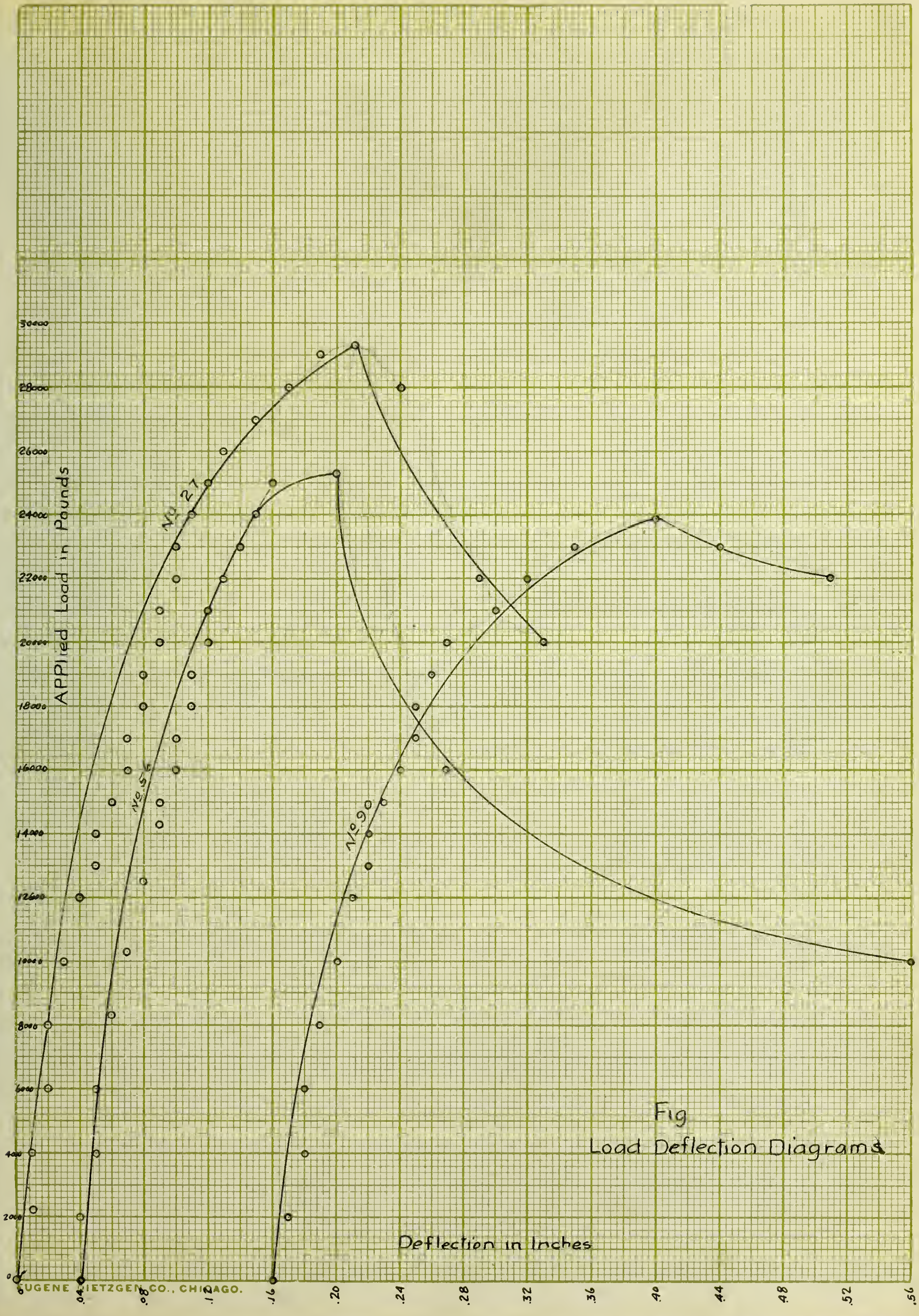
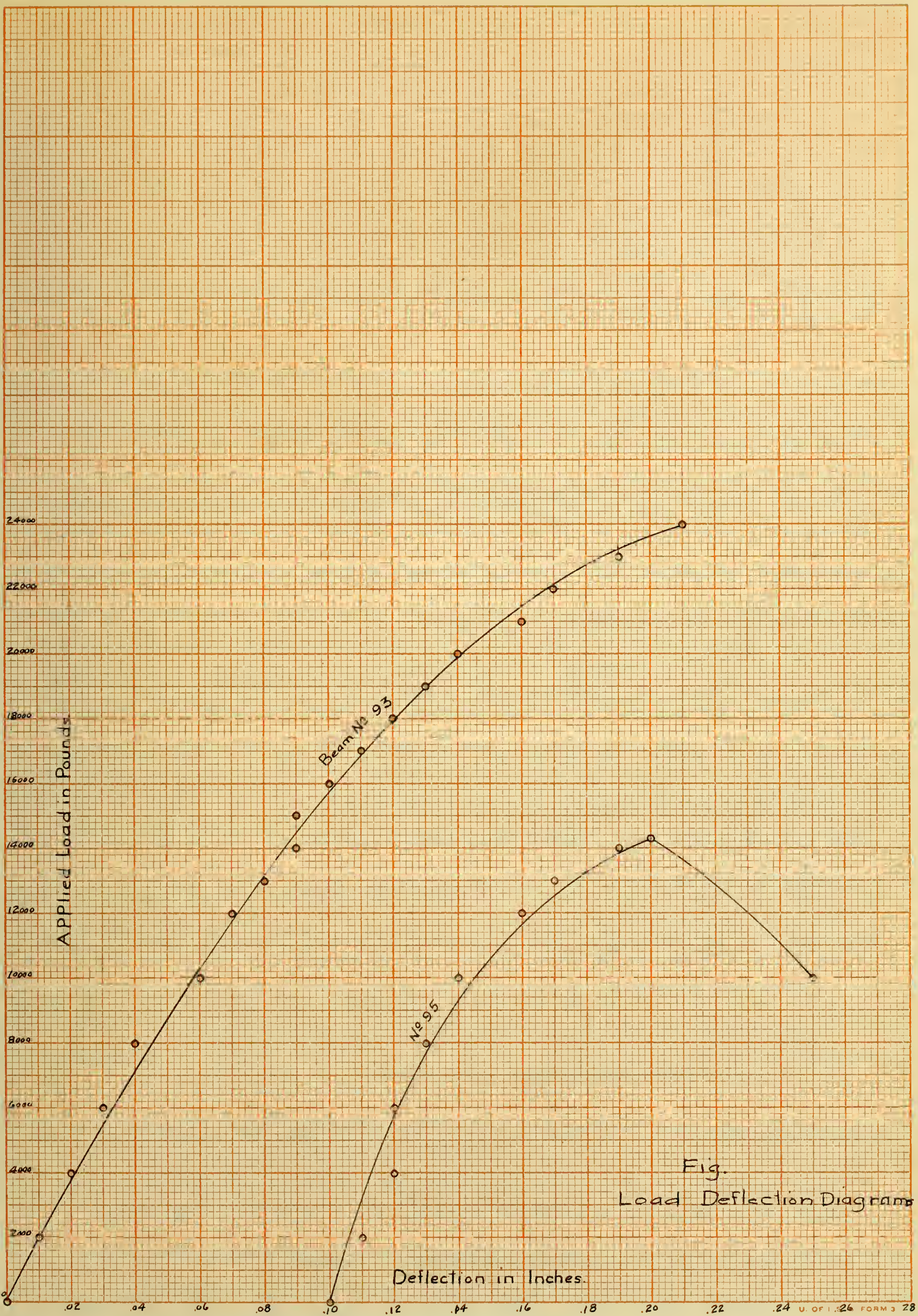


Fig
Load Deflection Diagrams



APPlied Load in Pounds
30000
28000
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
No. 27
No. 56
No. 90
Fig
Load Deflection Diagrams
Deflection in Inches
0
.04
.08
.12
.16
.20
.24
.28
.32
.36
.40
.44
.48
.52
.56
EUGENE DIETZGEN CO., CHICAGO.



24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Applied Load in Pounds
Beam No 93
No 95
Fig.
Load Deflection Diagrams
Deflection in Inches.
.02
.04
.06
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
28
U. OF I. S. FORM 3

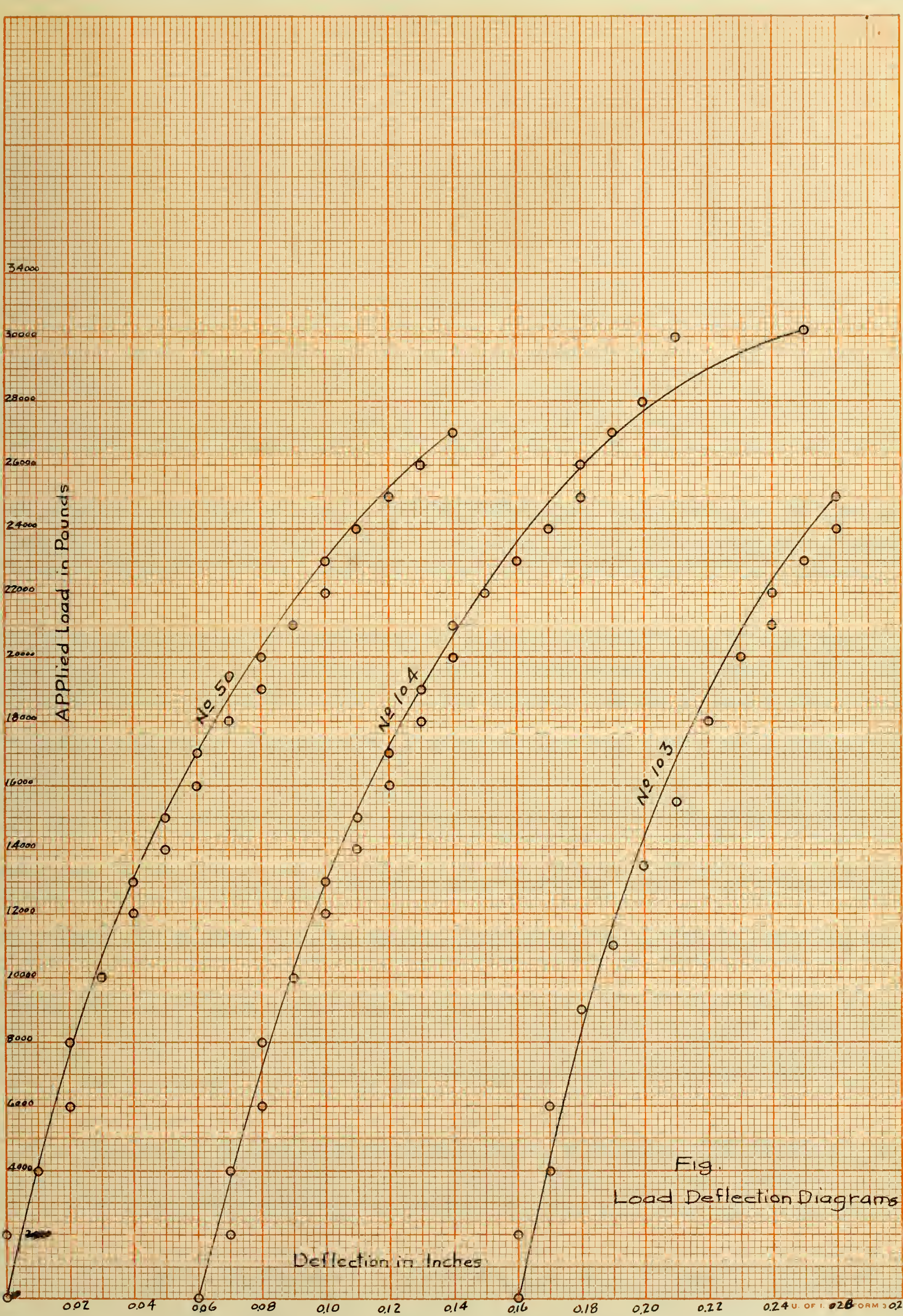


Fig.
Load Deflection Diagrams

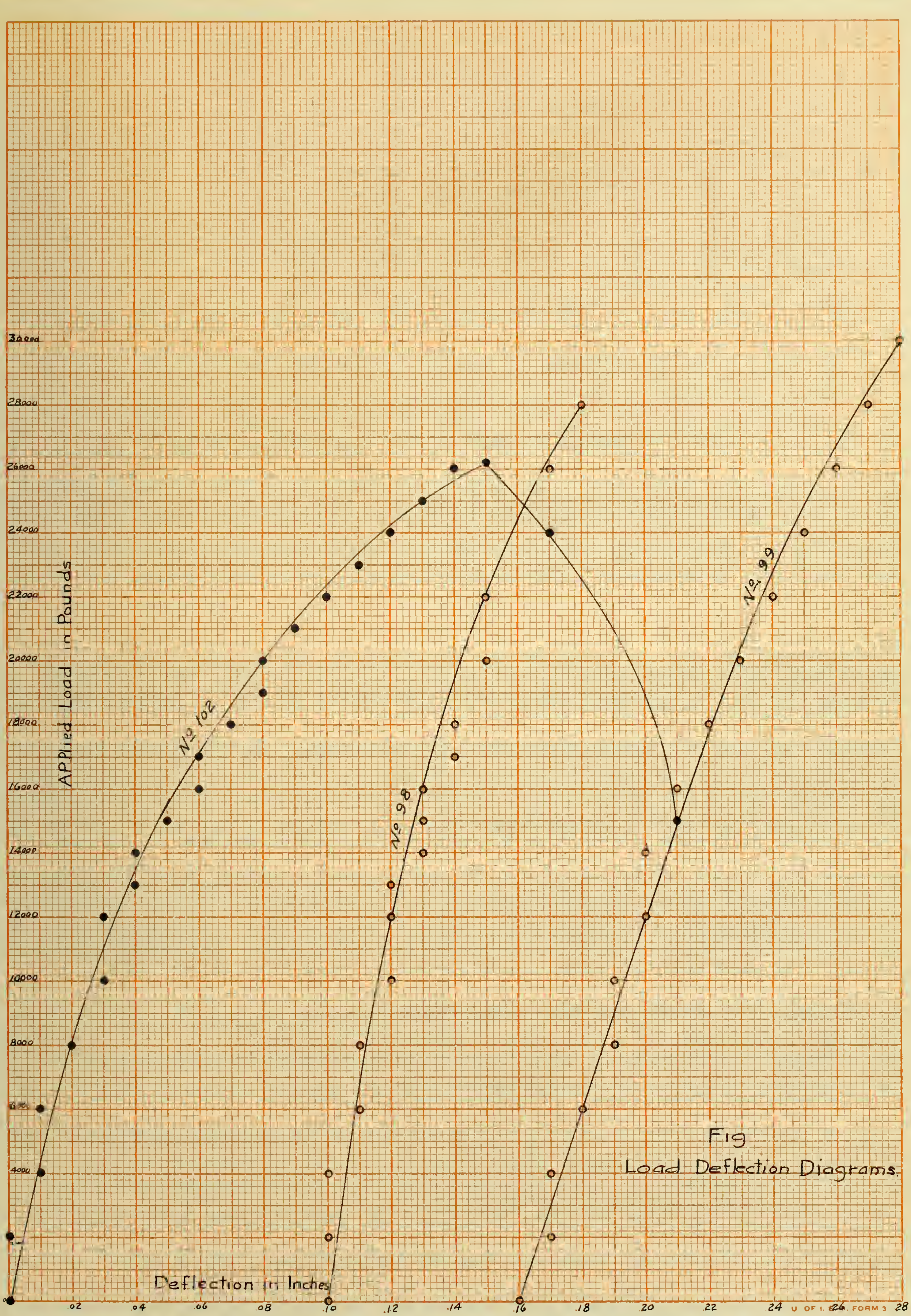
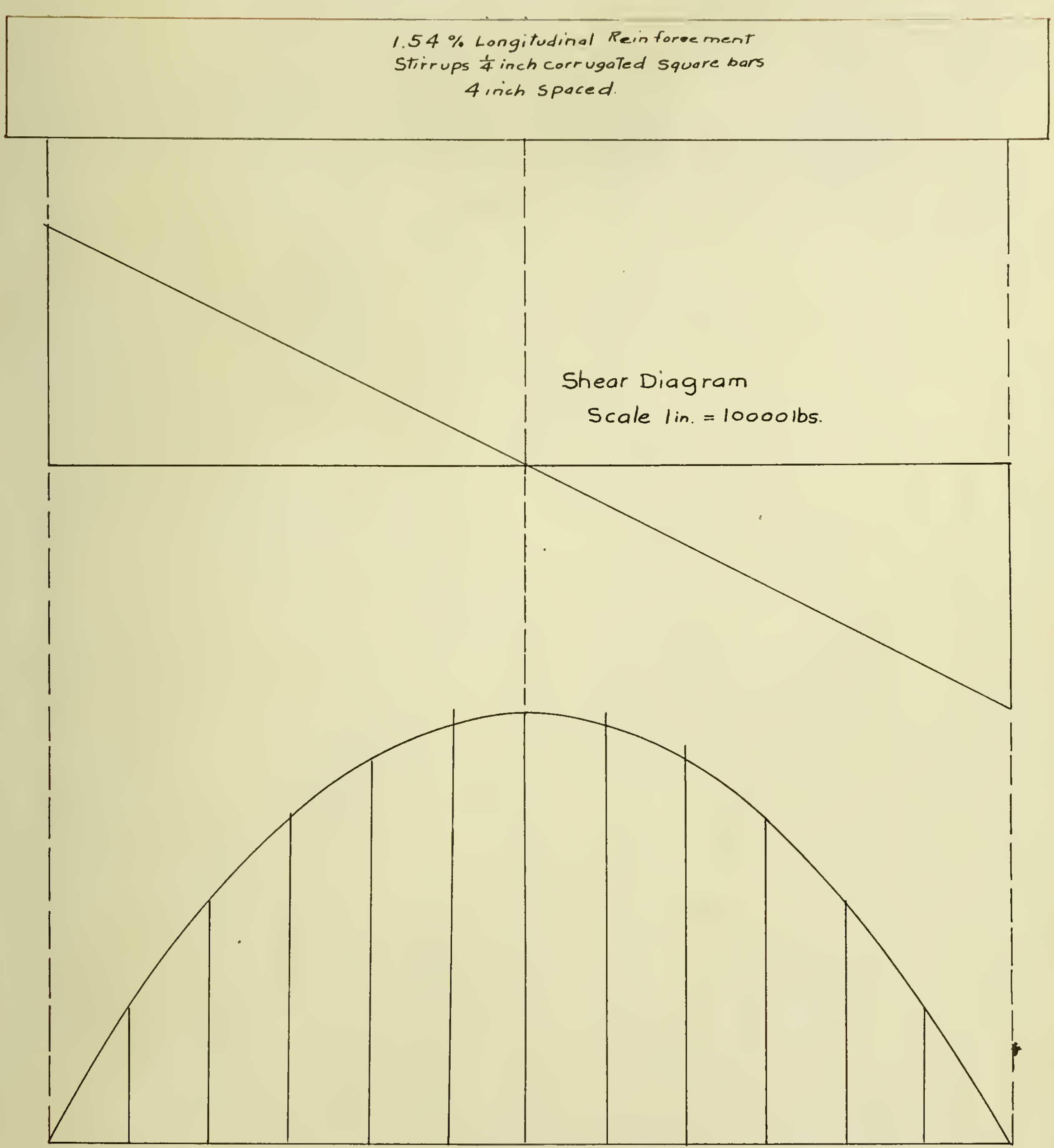


Fig
Load Deflection Diagrams.

Fig 2.

Beam No 98

Shear and Moment Diagrams.



Moment Diagram

Scale 1in = 100,000 in. poonds.

Beam No. 28.
Span 12'—0"
Loaded at one-third point.
Age 87 days. 1:2:4.

2.8% Reinforcement
Stirrups ½ in. corrugated squar bars
6 in. spacing.

Applied Load Pounds.	Deflection inches	Corrected Deflection inches	Extensometer No. 1. Top. inches	Extensometer No. 4 Bottom inches	Extensometer No. 3. Top. inches	Extensometer No. 2 Bottom inches
0	0.10	0.00	0.00	0.000	0.000	0.000
2000	0.13	0.03	0.044	0.033	0.032	0.044
4000	0.17	0.07	0.112	0.123	0.118	0.125
6000	0.22	0.12	0.119	0.211	0.213	0.210
8000	0.28	0.18	0.290	0.308	0.320	0.300
10000	0.34	0.24	0.348	0.414	0.490	0.395
12000	0.40	0.30	0.525	0.516	0.575	0.492
13000	0.47	0.37		0.605	0.690	0.582
14000	0.48	0.38		0.664	0.762	0.650
15000	0.52	0.42		0.730	0.855	0.718
16000	0.57	0.47		0.799	0.950	0.778
18000	0.68	0.58		1.035	1.227	0.935
19000	0.74	0.64		1.128	1.375	1.025
20000	0.82	0.72		1.224	1.565	1.125
21000	0.94	0.84		1.408	1.910	1.270
21300						

Beam № 98
Span 6'—0"
Loaded uniformly
Age 71 days
1 : 2 : 4 Mixture

1.54 % Reinforcement.
Stirrups ¼"▫ corrugated bars
4 inch spaced.

Applied Load Pounds	Deflection Inches	Corrected deflection inches	Height of Springs, inches		
			North End	Center	South end
0	1.86	0.00			
2000	1.86	0.00			
4000	1.86	0.00			
6000	1.85	0.01			
8000	1.85	0.01			
10000	1.84	0.02	7.25	7.15	7.15
12000	1.84	0.02	7.25	7.00	7.00
13000	1.84	0.02	7.25	7.00	7.00
14000	1.83	0.03	7.25	7.00	6.95
15000	1.83	0.03	7.15	6.95	6.90
16000	1.83	0.03	7.15	6.90	6.90
17000	1.82	0.04	7.15	6.90	6.80
18000	1.82	0.04	7.15	6.90	6.80
20000	1.81	0.05	7.00	6.75	6.75
22000	1.81	0.05	6.95	6.75	6.70
24000	1.79	0.07	6.90	6.70	6.70
26000	1.79	0.07	6.80	6.70	6.60
28000	1.78	0.08	6.70	6.60	6.50
30000					

Beam 99.

Span 6'-0"
Loaded uniformly
Age 71 days
1.54 % Reinforcement

Stirrups $\frac{1}{2}$ in. plain round
Sq. bars 6" spacing
1:2:4 mixture

Applied Load Pound	Deflection in Inches	Corrected Deflection in Inches	Height of Spring inches		
			North End	Middle	South End
0	2.09	0.00	7.50	7.40	7.50
2000	2.08	0.01	7.50	7.40	7.40
4000	2.08	0.01	7.40	7.30	7.30
6000	2.07	0.02	7.30	7.25	7.25
8000	2.06	0.03	7.25	7.15	7.20
10000	2.06	0.03	7.20	7.10	7.10
12000	2.05	0.04	7.15	7.05	7.10
14000	2.05	0.04	7.05	7.00	7.05
16000	2.04	0.05	7.00	6.95	7.00
18000	2.03	0.06	6.95	6.90	6.95
20000	2.02	0.07	6.90	6.85	6.85
22000	2.01	0.08	6.80	6.75	6.80
24000	2.00	0.09	6.75	6.75	6.75
26000	1.99	0.10	6.65	6.65	6.70
28000	1.98	0.11	6.65	6.60	6.65
30000	1.97	0.12	6.60	6.60	6.55
30500